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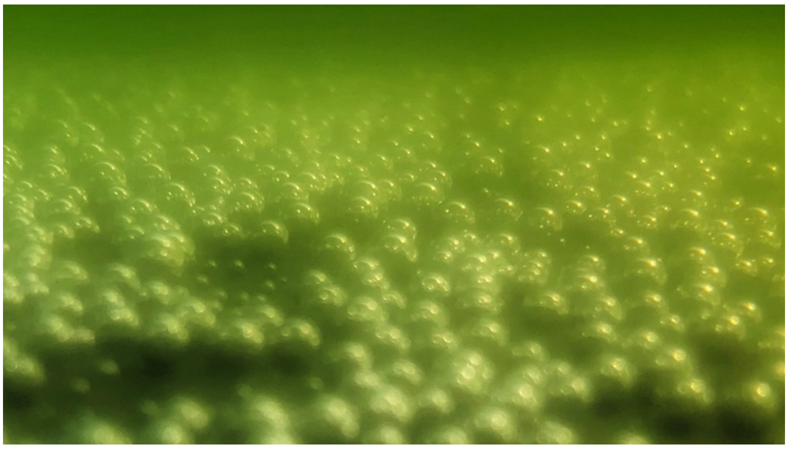
DEPARTMENT LIFE SCIENCES AND FACILITY MANAGEMENT

INSTITUTE ENVIRONMENT AND NATURAL RESOURCES

Sun Oxygen System

Oxygen supply in fish breeding ponds



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Abstract

Fish from aquaculture is becoming increasingly important for global food security. For the Cambodian population, fish is the most important source of animal protein. In 2014, the NGO Smiling Gecko Cambodia was founded. Through cooperation with the Zurich University of Applied Sciences, the Smiling Gecko Fish Project was launched 4 years later. In order to promote the education and income of surrounding smallholder women farmers and to counteract gender inequality, the Woman in Aquaculture project was launched. The Sun Oxygen System (SOS) was developed by the ZHAW to enable the planned fish breeding ponds to be aerated independently of the electricity grid. A pump powered by a solar panel transports the surface water, which is supersaturated with oxygen through photosynthesis by algae, into deeper layers. In this way, the excess oxygen does not immediately diffuse into the ambient air but can be stored for longer by the entire water column. For this work, a feeding trial with Nile tilapias was conducted in two fish ponds (water volume 468 m^3) to validate the benefits of the SOS. One pond was operated with an SOS, the other without. Besides daily measurements of dissolved oxygen (DO) concentration, water quality parameters were analysed and SOS performance was monitored. Due to excessive oxygen consumption at night and a clogged SOS pump, the trial was split into two trials. Trial A was started with a fish density of 0.96 kg/m^3 (1.7 kg/m^2). Trial B was continued with a fish density of 0.5 kg/m^3 (0.9 kg/m^2). The daily DO concentrations of the two ponds recorded during Trial B showed a 0.48 kg higher oxygen input during the day in the pond with SOS. However, this increased oxygen input was used up again overnight, so that the morning DO concentration with SOS was always lower from the 5th day (Trial B) of the trial than without SOS, and from the 7th day (Trial B) onwards no longer rose above 1 mg/l. Weighing the fish did not yield any useful data, as the feeding trial was stopped early in both trials due to the DO concentration being too low. The sample size of the weighed fish in both trials was considered too small to calculate a representative average weight, as the scatter of the weights was too large. Daily DO concentration curves were used to show the effect of SOS on pond water mixing. While without SOS a stratification with different DO concentrations takes place, with SOS the DO concentration is balanced in the evening. An analysis of the SOS performance showed that on sunny days a power surplus of 0.86 kWh is produced, which can be used for additional energy consumers. The reasons for the high oxygen consumption overnight were then discussed. Possible solutions were identified and design changes were proposed for further SOS tests.

Zusammenfassung

Fisch aus Aquakulturen gewinnt immer mehr an Bedeutung für die weltweite Ernährungssicherheit. Für die kambodschanische Bevölkerung bedeutet Fisch die wichtigste tierische Proteinquelle. 2014 wurde die NGO Smiling Gecko Cambodia gegründet. Durch die Zusammenarbeit mit der Zürcher Hochschule für angewandte Wissenschaft konnte 4 Jahre später das Smiling Gecko Fish Project gestartet werden. Um die Ausbildung und das Einkommen umliegender Kleinbäuerinnen zu fördern und der Ungleichstellung der Geschlechter entgegenzuwirken, wurde das Projekt Woman in Aquaculture lanciert. Damit die Belüftung der hierfür geplanten Fischzuchtteiche unabhängig vom Stromnetz erfolgen kann, wurde von der ZHAW das Sun Oxygen System (SOS) entwickelt. Durch eine mit einem Solarpanel betriebene Pumpe wird das durch die Photosynthese von Algen mit Sauerstoff übersättigte Oberflächenwasser in tiefere Schichten befördert. So diffundiert der überschüssige Sauerstoff nicht gleich in die Umgebungsluft sondern kann im Teichwasser länger gespeichert werden. Für diese Arbeit wurde in zwei Fischteichen (Wasservolumen 468 m^3) ein Fütterungsversuch mit Nil-Tilapias durchgeführt um den Nutzen des SOS zu validieren. Der eine Teich wurde mit einem SOS betrieben, der andere ohne. Neben täglichen Messungen der Sauerstoffkonzentration wurden Wasserqualitätsparameter analysiert und die SOS Leistung überwacht. Aufgrund zu hoher Sauerstoffzehrung in der Nacht und einer verstopften SOS Pumpe wurde der Versuch in zwei Versuche geteilt. Trial A wurde mit einer Fischdichte von 0.96 kg/m^3 (1.7 kg/m^2) gestartet. Trial B wurde mit einer Fischdichte von 0.5 kg/m^3 (0.9 kg/m^2) weitergeführt. Die während Trial B täglich erhobenen Sauerstoffkonzentrationen zeigten im Teich mit SOS einen um 0.48 kg höheren Sauerstoffeintrag während des Tages. Der erhöhte Sauerstoffeintrag wurde jedoch über Nacht wieder verbraucht, sodass die morgendliche Sauerstoffkonzentration mit SOS ab dem 5. Versuchstag (Trial B) immer tiefer lag als ohne SOS und ab dem 7. Tag (Trial B) nicht mehr über 1 mg/l stieg. Das Wiegen der Fische ergab unbrauchbare Daten, da der Fütterungsversuch in beiden Versuchen aufgrund der zu geringen Sauerstoffkonzentration frühzeitig abgebrochen wurde. Die Stichprobengrösse der gewogenen Fische in beiden Versuchen wurde als zu klein erachtet um ein repräsentatives Durchschnittsgewicht zu errechnen, da die Streuung der Gewichte zu gross war. Anhand von Tageskurven der Sauerstoffkonzentration konnte die Auswirkung des SOS auf die Wasserdurchmischung des Teiches aufgezeigt werden. Während ohne SOS eine Stratifizierung mit unterschiedlichen Sauerstoffkonzentrationen stattfindet, ist mit SOS die Sauerstoffkonzentration abends ausgeglichen. Eine Analyse der SOS Performance ergab, dass an sonnigen Tagen ein Stromüberschuss von 0.86 kWh produziert wird, welcher für zusätzliche Energieverbraucher genutzt werden kann. Die Gründe für die hohe Sauerstoffzehrung über Nacht wurden anschliessend diskutiert. Es werden Lösungsansätze aufgezeigt und Konstruktionsänderungen für weitere SOS Tests vorgeschlagen.

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1 Introduction

Due to overfishing of waters, rising temperatures caused by climate change aquaculture is becoming increasingly important for food security. In recent years, the production volume of aquacultures has increased worldwide. However, the greatest growth is being achieved by developing countries. In the whole of Africa and Asia (excluding China), the production volume rose by around 7% between 2016 and 2018. For these countries, fish is a very important food. In Bangladesh, Cambodia, Gambia, Ghana, Indonesia, Sierra Leone and Sri Lanka, fish accounts for over 50% of per capita consumption of animal protein (The State of World Fisheries and Aquaculture 2020). In 2014, Smiling Gecko Cambodia (SGC) was founded as a local NGO with the aim of supporting the local population with direct aid and sustainable help for self-help. In the province of Kampong Chhnang a 110 ha plot of land was purchased for this purpose. This area is to serve as training and work place in the sectors of agriculture, tourism, industry and handicraft. With the support of the Zurich University of Applied Sciences (ZHAW), the Smiling Gecko Fish Project could be integrated in 2018 (Smiling Gecko n.d.). According to Ben Scott (2020), up to 25 tonnes of Nile tilapia (Oreochromis niloticus) can be cultivated annually for own consumption and the local market. Within the Smiling Gecko Project Woman in Aquaculture, the project "Sun-Oxygen-System: Energy Efficient Fishpond Aeration Enhancing Integrated Small-scale Farming in Cambodia" was launched by the ZHAW through the collaboration with the Asian Institute of Technology, the organisation Word Fish and the project funding platform REPIC. The aim is to help agricultural enterprises integrated in the project to achieve ecological and sustainable fish farming which can be operated off-grid. This promotes the training and income of small-scale farmers and is intended, among other things, to counteract gender inequality in Cambodia by recruiting female farmers. Food security in Cambodia's rural communities will also be improved, since during the dry season the water from the breeding ponds can also be used to irrigate the surrounding fields (Tschudi 2020). The Sun Oxygen System (SOS) was developed at the ZHAW for the oxygenation of fish ponds independently of the electricity grid. Thanks to this system, the naturally occurring dissolved oxygen (DO) in aquaculture ponds can be utilised in a better way. The aim of this work is to validate the SOS on site in Cambodia. For this purpose a feeding trial with tilapias will be launched on the premises of Smiling Gecko Cambodia. For this field trial, two stocked fish ponds are available. One of them is to be managed with an SOS and the other without. Daily monitoring of the DO concentrations in the water, the fish behaviour and the SOS runtime will be used to evaluate the performance and benefit of the Sun Oxygen System. Other chemical water parameters will be collected to check the water quality during the trial. All results obtained will be analysed and discussed below. A subsequent conclusion completes this work.

2 Theory

This chapter is intended to provide the reader with the necessary background information, with the help of literature, to better understand the procedure and the results of this work. This is followed by information about the fish species used in the later experiment. The importance of DO in fish farms and different systems for oxygen input are discussed. The interaction of phytoplankton communities and the oxygen content in the water is also explained. Finally, the functioning of the Sun Oxygen System used for the experiment is briefly described.

2.1 Tilapia in aquaculture

Tilapia (Oreochromis niloticus) has a high potential to be farmed as a food fish in aquacultures due to its good characteristics such as easy handling in hatchery production, resistance, tolerance to high stocking densities and rapid growth (Hussain 2004). Besides carp, it is therefore the most farmed fish worldwide. Tilapia accounted for 8.3 % of all fish produces in aquaculture worldwide in 2018. The production is constantly increasing. The annual production in 2018 was 4`525`400 tons. This represents a 12-fold increase since 1990 (The State of World Fisheries and Aquaculture 2020).

Originally the Tilapia was found on the African continent. It is therefore well suited to be bred in warmer regions. Tilapias can survive in waters with water temperatures of 11- 42 degrees Celsius (Pullin and Lowe-McConnell 1982). Such high water temperatures lead to very low levels of DO in natural waters (Lewis 2018). Abdel-Tawwab et al. (2015) show that tilapias can survive at low DO concentrations of 1.0 1.5 mg/L, but that this has a significant negative impact on the growth, health and survival rate of the fish.

At low DO levels, fish feed intake and growth is limited by the oxygen uptake capacity (Pauly 2010). For this reason, fish should not be fed if the DO content is too low. Otherwise further oxygen consumption will occur due to the increased metabolism of the fish and the microbial decomposition of the spurned fish food and fish may die due to lack of oxygen (Boyd 2018).

Another important criterion for healthy fish in aquaculture is stocking density. Many farms achieve better economic performance through high stocking densities, but are dependent on the use of drugs and antibiotics (Carvalho, David, and Silva 2012). Studies by Garcia et al. (2013) on tilapias show that by reducing the stocking density from 100 kg/m^3 to 30 kg/m^3, growth performance and feed conversion rate were significantly improved. In addition, the time to reach the crop yield was shortened and production costs were reduced. The fish were also less prone to disease and the mortality rate was reduced even without the use of drugs. Thanks to these findings, an increase in operating profit is possible.

The tilapia breeding of Smiling Gecko Cambodia has been continuously expanded and improved since 2018. According to Fridolin Tschudi (2021) the tilapias are bred here according to Naturland guidelines which prescribe stocking densities of up to 10 kg/m^3 except for the feed (Naturland Richtlinien 2020). This is also within the range of Swiss organic guidelines. These prescribe a stocking density of less than 20 kg/m^3 (Brändli 2021). Over the year the tilapia pond is exposed to a fluctuation of the DO concentration between 1.1 mg/l and 12.7 mg/l (data 2019, measuring time approx. 16:00, measuring depth 1m). The aquaculture ponds are aerated with paddle-wheels, which transport additional oxygen into the surface water, especially at night. At very low DO concentrations (below 2 mg/l), fish feeding is suspended and the paddle-wheels are increasingly operated during the day. If the DO concentration in the pond drops to 1 mg/l, this can be seen very clearly by the fish gulping at the water surface.

2.2 Oxygen supply in aquaculture

As shown in the previous chapter an increased DO concentration in the water can increase the production in an aquaculture and thus its profitability. In intensively managed aquacultures aeration costs are therefore the third largest cost component after larvae and feed (Kumar, Moulick, and Mal 2013). The supply of pure oxygen is often used in such breeding (Colt and Watten 1988). Higher saturation values can be achieved by such a fumigation than if the water is only aerated with ambient air. However such a procedure requires a technically complex implementation and is very cost-intensive. In addition to the use of diffusers and diffusers which are coupled to compressed gas cylinders compressors or oxygen generators for aeration and gassing there are also technically simpler aeration methods.

So-called trickle cascades work on the principle of increasing the contact surface of the water to be enriched in order to improve the gas exchange with the ambient air. Spray aerators, paddle-wheel aerators and propeller aerators are often used in pond management to intensify the air contact at the water surface (Gerbeth and Gemende 2005).

Such paddle-wheels are widely used for aeration of pond farms in developing countries among others thanks to their efficiency, simplicity and low cost (Hussain 2004).

To compare the aeration performance of such different aeration systems, there are steady-state and unsteady-state tests. In steady-state tests, the aeration systems are mounted in a water flow and the DO concentration is measured before and after. However, this is rather difficult to implement, especially with large surface aerators. For the unsteady-state test, a water basin with clean water is aerated with sodium sulphate. After the subsequent re-enrichment by the aeration system to be tested, the DO concentration can be measured. A common coefficient to compare aeration systems is the standard oxygen transfer rate (SOTR). It is defined as the amount of

oxygen transferred to the water per hour under standard conditions (0 mg/l O_2, 20 C°, clean water). If SOTR is divided by the energy used, the standard aeration efficiency (SAE) is obtained, which indicates with how many kg O_2 the ambient water is enriched per kWh (Boyd 1998).
In the tilapia farm of Smiling Gecko Cambodia the ponds are aerated with paddle wheels since March 2019. Due to the experience since the installation disadvantages of this method also became apparent here. As the paddle-wheels are operated with electrical energy further high operating costs are incurred here. In the event of interruptions and fluctuations in the local power grid diesel generators must also be used. Since the paddles are located near the water surface the oxygen enrichment and circulation of the deeper water layers in a pond is not very high (Boyd and Tucker 1998). Paddle wheels are most effective at night when there is little DO in the pond water. Therefore they are not suitable for direct solar energy operation (Tschudi 2020). During operation throughout the day valuable oxygen introduced to the water surface by the photosynthesis of phytoplankton can also be released at a high degree of saturation (Scott 2020).

2.3 Oxygen production of phytoplankton

Through the growth of algae and other phytoplankton in water molecular oxygen as a by-product of photosynthesis is released into the surrounding water (Smith and Piedrahita 1988). In this process the chlorophyll in phytoplankton converts solar energy into ATP (adenosine triphosphate) which is used to reduce inorganic carbon (CO_2) to organic carbon in the form of sugar. Photosynthesis can be summarised as follows [F1] (Boyd and Tucker 1998):

[F1]

$$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

In this way phytoplankton is the main source of DO in fish ponds. At the same time this photoautotrophic plankton is one of the most important oxygen sinks. On the one hand this happens directly as a consumer of oxygen through cell respiration at night and on the other hand through the decomposed organic substance which is further decomposed by bacteria under oxygen consumption (Smith and Piedrahita 1988).
Cell respiration is the process by which oxygen dissolved in water is needed for biological work so that phytoplankton can grow maintain and reproduce. The oxidation process of respiration is ecologically speaking a reverse photosynthesis and is represented by the following reaction equation [F2]:

[F2]

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{heat energy}$$

Uncontrolled growth of phytoplankton communities causes most water quality problems in aquaculture ponds due to this imbalance in oxygen balance. An excessively large phytoplankton population can lead to high oxygen consumption at night. The fish are then exposed to increased stress due to the very low DO values (Boyd and Tucker 1998).

In addition to this imbalance in DO concentration which is caused by photosynthesis during the day and respiration at night there are also differences in DO concentration and saturation in different water depths of aquaculture ponds during the day. As the light intensity decreases with increasing water depth the growth of phytoplankton in deeper layers also stagnates. The photosynthesis of the plankton is also influenced by the light intensity (Goldman 1965). This results in a higher DO concentration in the uppermost water layers of a pond when there is a high level of solar radiation. A study by Phan-Van, Rousseau, and De Pauw (2008) showed that in a tilapia pond in Vietnam, oxygen saturation of up to 200% was reached during the dry season over the midday hours at a water depth of 20 cm while saturation at a depth of 80 cm rose to 60%.

As the DO concentration in the water depends on the air pressure and temperature the maximum DO concentration at 100% saturation a water temperature of 31 C and a height of 38 m.a.s.l. (situation Smiling Gecko Cambodia) is 7.4mg/l (Lewis 2018). A higher DO content resulting from a saturation of over 100%, as mentioned above diffuses back into the ambient air over time. This surplus produced by the phytoplankton could be used to improve the DO content in the entire pond.

2.4 Sun Oxygen System

The Sun Oxygen System (SOS) was developed to transport the oxygen-saturated water of a pond surface into deeper layers. In this way the excess oxygen is not directly diffused back into the ambient air but can be used for fish production.

In 2020 an SOS was produced as a prototype at the Zurich University of Applied Sciences on the basis of a bachelor thesis and tested under laboratory conditions (Christen 2020). An SOS consists of the following four main components: A float, a solar module, a pump and a 1.5 m long pipe. The pump driven by the solar module sucks in the oxygen-rich surface water and transports it through the pipe into deeper water layers. The mode of operation is shown in simplified form in Figure 1.

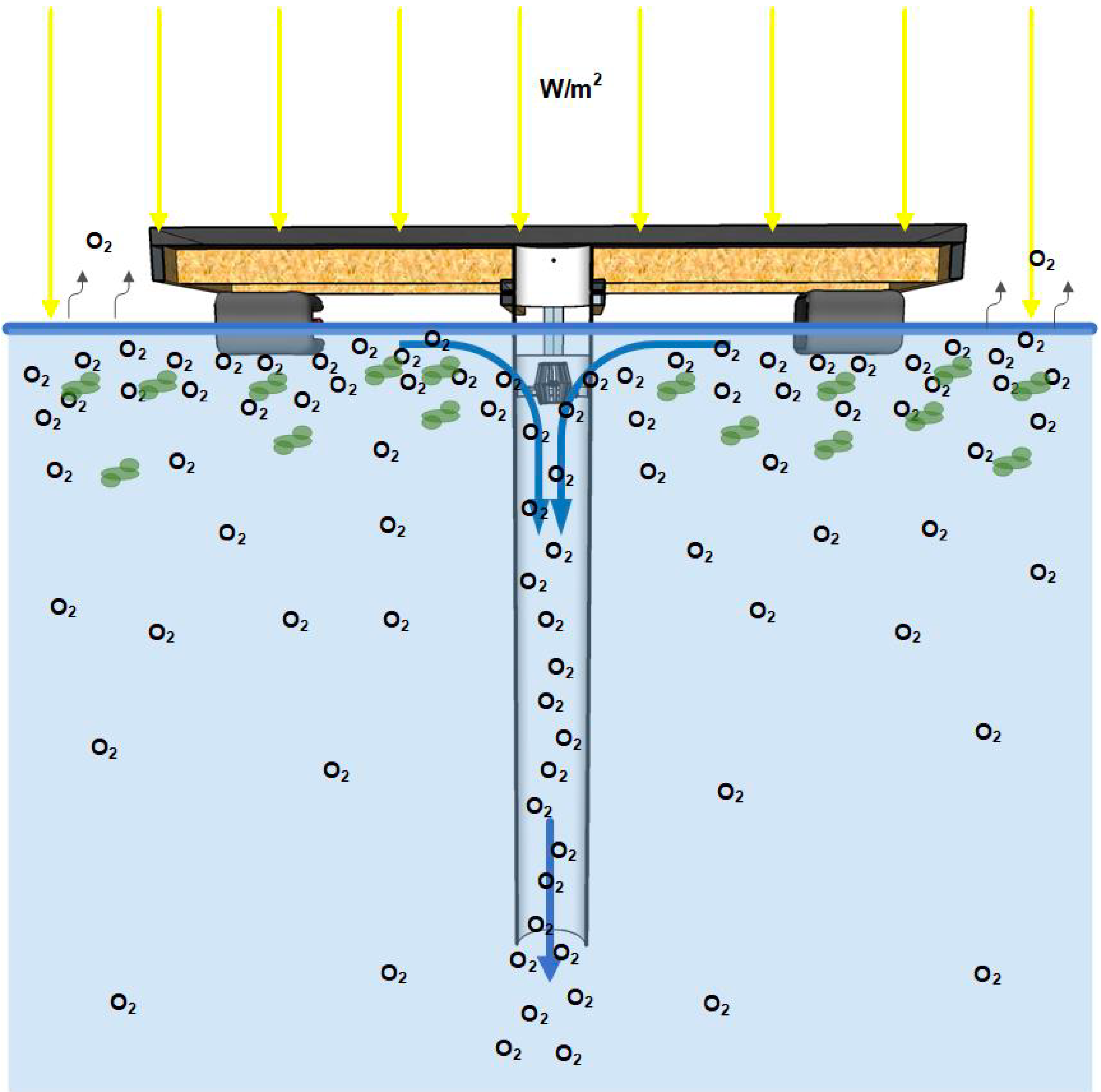

Figure 1: Mode of operation from SOS. Surface water enriched with oxygen by algea which is pumped into deeper layers by means of solar panels. Solar radiation (yellow), water flow (blue), algea (green) (Christen 2020)

Based on climate data from Cambodia an SOS in which a 230 Wp solar module was installed should in theory be in operation for an average of 8 hours a day and circulate the pond water (Christen 2020).

3 Material and Methods

This chapter describes the methodology of this thesis and shows with which materials and under which conditions the experiments for this bachelor thesis were carried out.

3.1 Fish pond dimension and situation

Two ponds were available for the field trial, which were lined with pond liners in advance (Figure 2). The fish ponds were filled to a depth of 2.6 m with water from the neighbouring tilapia farm. This corresponded to a volume of 468 m^3. In Pond 1 an SOS was fixed in the middle (Figure 2). Concrete blocks (25 kg) were made on each side of the pond and a rope was tied to the SOS.

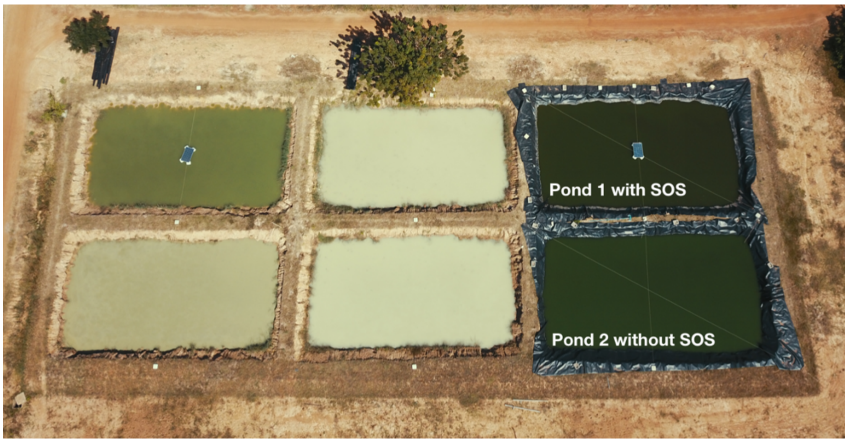

Figure 2: Pond situation Smilling Gecko Cambodia. Pond 1 with SOS / Pond 2 without SOS

The shape of the ponds is equal to a rectangular truncated pyramid with 45° angles and the following dimensions (Figure 3).

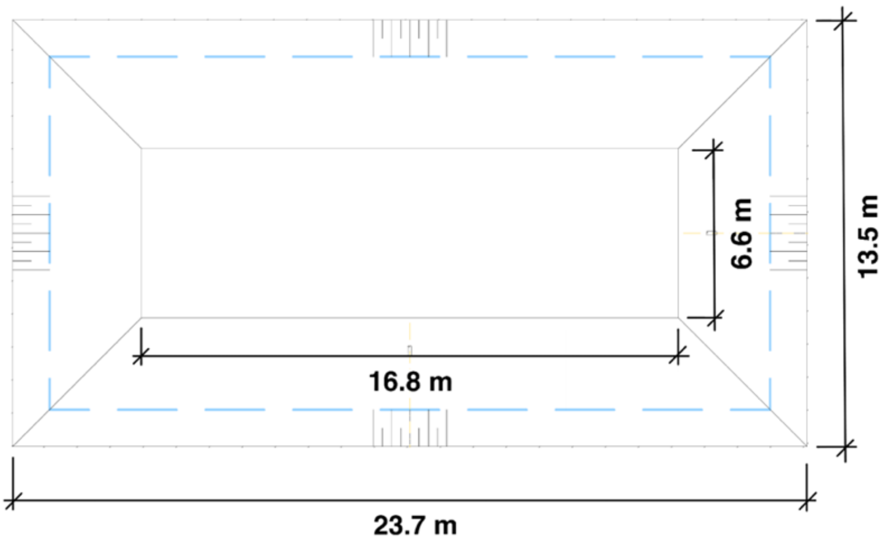

Figure 3: Dimensioning of the fish ponds

3.2 Sun Oxygen System assembly and components

The Sun Oxygen System (Figure 4) used in this work consists of the following main components (Table 1) and was assembled on site according to our own instructions (Appendix A and B).

Table 1: Most important SOS components and specifications

Component	Specification
Solar panel	JKM275PP-60
Pump	Jebao RW-20
Step Down Modul	300 W 20 A DC-DC Converter
Metal frame	1650 mm x 990 mm (25x25 mm profile)
PVC Pipe	1500 mm (Ø 160 mm)
4 x Canister	20 l
Plastic Box for electronics	1.1 l

Figure 4: Sun Oxygen System with steel frame, electrical components (red box) and Pump-Pipe (blue tube)

A detailed list of materials including Cambodian prices can also be found in the appendix (Appendix C).

3.3 Fish stocking

Nile tilapias (Oreochromis niloticus) were used for the experiment. In order to ensure a uniform size of the fish, they were sorted in advance. To do this, the weight and length of 100 fish weighing around 300 g were recorded. This made it possible to produce a stock measure which simplified the manual sorting of the fish. Since the fattening farm did not have enough 300 g fish, a trend line was created in order to adjust the stock measure to 250 g fish.

Before the start of the trial, 450 kg (approx. 1800 fish) of the pre-sorted fish were transferred to Ponds 1 and 2 using a scale (Scale NHON HOA 100 kg, +/- 200 g). This corresponded to a fish density of 0.96 kg/m^3 in a volume of 468 m^3 and a density of 1.7 kg/m^2 for the water surface of 259.6 m^2.

3.4 SOS Trials

The SOS trial started on 5. November and ran until 16. December 2020. Due to problems encountered (see discussion, Trial A), the trial was split into Trial A (05.11.20 - 26.11.20) and Trial B (02.12.20 - 16.12.20). For Trial B, more than half of the fish were transferred from the ponds. The experiment was then continued with 234 kg of fish per pond. This corresponded to a density of 0.5 kg/m^3 and 0.9 kg/m^2.

As the SOS pump can be set to different speed levels and the trial start took place in the rainy season under bad weather conditions, the speed of the SOS pump was lowered to level 5 of 8 during Trial A. This ensured a longer runtime of the SOS despite heavy cloud cover, as the pump motor consumes less power (see results, SOS performance).

3.4.1 Monitoring of SOS performance, oxygen and water chemistry measurements

To check the function of the SOS, a voltage data logger (VOLTCRAFT DL-191V) was used. The current was recorded in an 5 min interval during the test. In order to measure the current of the running motor, a 0.1 Ohm resistor (CRA2512-FZ-R100ELF) was installed behind the step down module. The voltage was then measured via this resistor to determine the required amperage of the pump (Figure 5).

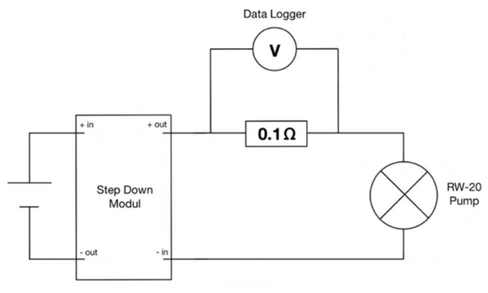

Figure 5: Electrical schematic of voltage measurement

In addition, the solar radiation was recorded every 5 min with a solar data logger (VOLTCRAFT DL-131). 9 W/m^2 were added to the logged values. Since the logger was protected from rain with a glass, this reduced the solar radiation by 9 W/m^2 (Figure 6).

Figure 6: Solar data logger with protection glas

In advance, a test was launched to show how much power-input the pump of the SOS can operate without problems, as the motor of the pump stalls when the solar radiation is too low. For this purpose, the solar radiation was logged every minute at sunrise with the above-mentioned solar data logger and thus checked on site at the installed SOS at how many W/m^2 the pump starts. The required solar radiation was determined for speed levels 5 and 8 (highest level).

DO concentration, saturation and water temperature were measured four times a day (06:30, 09:30, 13:30, 15:30) with an oxygen probe (Hach HQ40d, LDO) at depths of 0.02, 0.5, 1 and 2 m. With the help of a floatable extension (Figure 7), measurements were taken in the middle of the pond long side 3 m from the shore at point 4 in Figure 8.

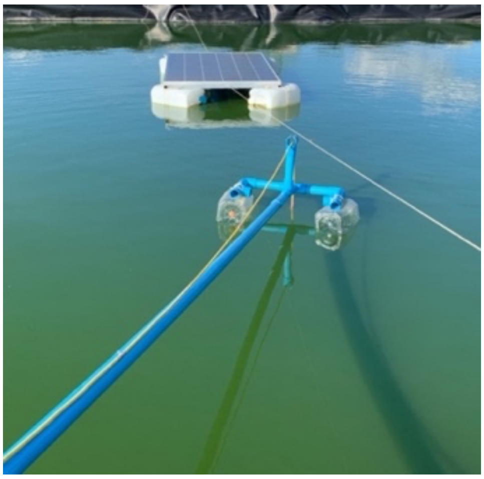

Figure 7: Floatable extension for DO measurement

In order to get a more accurate picture of the DO distribution, the DO concentration was additionally measured twice a week in the entire pond during experiment B. The DO concentration was measured in the same water depths at sites 1 - 5 with the help of a rubber boat at 06:30, 09:30, 13:30, 15:30 and 17:30 and the following day at 06:30 (Figure 8).

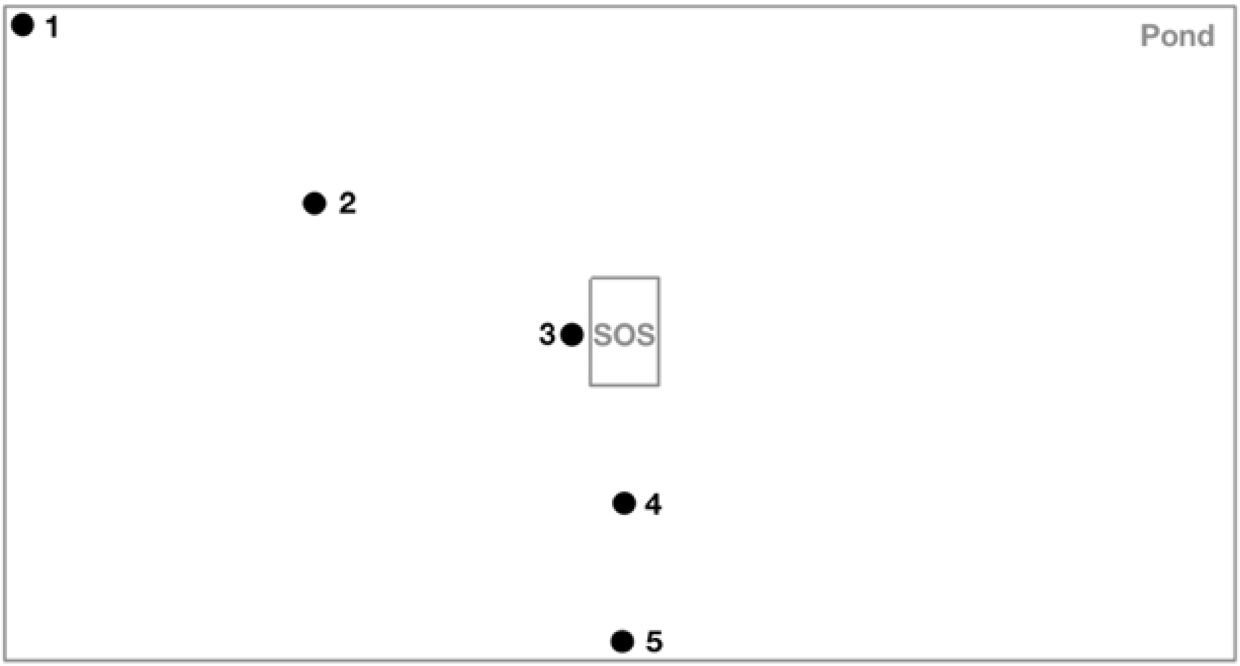

Figure 8: Distribution measurement points in Pond 1 and 2

During the trial, the following water quality parameters were also monitored (Table 2).

Table 2: Method and frequency of the measured water quality parameters during experiment A and B

Trial	Measurements	Attributes	Unit	Method
A & B	1 x per week	pH	-	Hach HQ40d
A & B	1 x per week	temperature	C°	Hach HQ40d
A & B	1 x per week	conductivity	ms/cm	Hach HQ40d
A & B	1 x per week	turbidity	FNU	Hach HQ40d
A & B	1 x per week	TAN-N	mg/l	Hach Salicylate
A & B	1 x per week	NO_2-N	mg/l	Hach NitriVer 3
A & B	1 x per fortnight	PO_4-P	mg/l	Hach PhosVer 3
A & B	1 x per fortnight	COD	mg/l	Hach ISO 15705
B	1 x per week	NO_3-N	mg/l	Hach NitraVer 5

The water samples were always drawn at 13:30 at a depth of 10 cm and transported to the laboratory for analysis using a cool bag.

3.4.2 Feeding and fish weight

The daily feeding amount for the experimental ponds was calculated in a feeding plan. Based on the starting weight of the fish, an initiated FCR (feed conversion ratio) and the amount of feed fed the previous day, the weight gain of the fish was calculated automatically. This allowed the feed quantity to be calculated via the feed intensity (percentage of body weight) [F3] and then weighed (Scale NHON HOA 2000 g, +/- 10g).

[F3]

$$Fq = Fi * (W_{db} + \frac{W_{db} * Fi_{db}}{FCR})$$

Fq = Feed quantity (kg)
Fi = Current feed intensity (%)
Fi_{db} = Feed intensity day before (%)
W_{db} = Weight day before (kg)
FCR = Feed conversion ratio

Based on the daily DO measurements, the oxygen input by phytoplankton and the nocturnal oxygen consumption could be estimated for the current day. Thus, the feeding intensity was steadily increased until the DO concentration in the fish pond reached a set minimum of 1 mg/l the following morning.

Every fortnight, fish were caught from the ponds using a drag net and weighed individually using a hanging scale (Scale WH-A03L, Weiheng Electronics Co. +/- 5 g). In experiment A, 50 fish per pond were weighed. In experiment B, the sample size was increased to 200 fish, as the scatter of the individual fish weights was very high.

3.5 Data evaluation

The following formulas in this chapter should help to understand the results. All the data obtained and their evaluation as well as the calculations for the feeding plans discussed in the previous chapter can be found under the following link:

https://zhaw-my.sharepoint.com/:f:/g/personal/konrajon_students_zhaw_ch/Eq6mjkcwKLhAsWgGTkPt19UBhtGQjncGI2_ovj1eMLmHjw

3.5.1 Calculation of total oxygen input

In order to estimate a possible increased input of oxygen by the SOS, the total oxygen balance in the ponds was calculated on the basis of the collected DO concentrations [F4]. For this purpose, the DO content in the entire pond was first calculated for the times of day 06:30 and 15:30.

[F4]

$$O2_{total} = \frac{\frac{O2_{2.6\,m} + O2_{2.1\,m}}{2} * (V_{2.6\,m} - V_{2.1\,m}) + \frac{O2_{2.1\,m} + O2_{1.6\,m}}{2} * (V_{2.1\,m} - V_{1.6\,m}) + \frac{O2_{1.6\,m} + O2_{0.6\,m}}{2} * (V_{1.6\,m} - V_{0.6\,m}) + O2_{0.6\,m} * V_{0.6\,m}}{1000}$$

$O2_{total}$ = Total DO content (kg)
$O2_{x\,m}$ = DO concentration at x metres pond height (mg/l)
$V_{x\,m}$ = Pond volume at x metres (m^3)

The following diagram of a pond cross-section should help to better understand the above calculation (Figure 9).

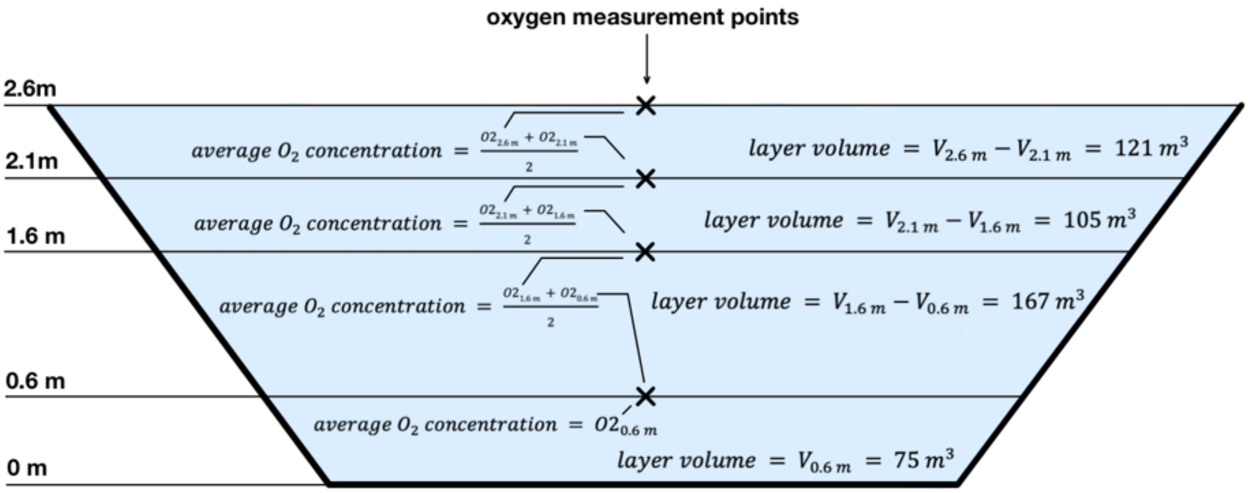

Figure 9: Figure of a pond cross-section with calculation of average DO concentration and layer volume

Then the difference in DO content between 06:30 and 15:30 was taken. In this way, the total oxygen input over the day from both ponds could be compared [F5].

[F5]

$$O2\ total\ P1_{15:30} - O2\ total\ P1_{06:30} \neq O2\ total\ P2_{15:30} - O2\ total\ P2_{06:30}$$

$O2$ total $P1/P2_x$ = Total DO content (kg) of Pond 1 or Pond 2 at time x

3.5.2 Calculation of produced and consumed Watts

In order to estimate the energy production of the solar panel used, it was assumed that the power of the panel decreases linearly with the solar radiation (Christen 2020). The amount of energy produced was calculated as follows for the 275 Watt used [F6]:

[**F6**]

$$W_{produced} = \frac{275\ W}{1000\ W/m^2} * Solar\ radiation\ (W/m^2)$$

W$_{produced}$ = amount of energy (W) produced by the solar panel

The amount of energy consumed by the SOS pump was determined by the voltage measured via the upstream resistor [F7].

[**F7**]

$$W_{consumed} = A_{Widerstand} * 24\ Volt$$

W$_{consumed}$ = amount of energy (W) consumed by the SOS pump

A$_{Widerstand}$ = $\frac{V_{Widerstand\ (0.1\ Ohm)}}{0.1}$

4 Results

The following chapter shows and describes the data and results collected during the trial.

4.1 Trial A

Figure 10 shows the course of the DO concentrations in the morning at 06:30 of Trial A from day 1 to 22. The DO concentrations up to day 14 could not be recorded because there was no functioning probe. The measured DO concentrations in the ponds were below 1 mg/l. The fish were gulping for air in both ponds from day 11. From the same day onwards the fish were no longer fed.

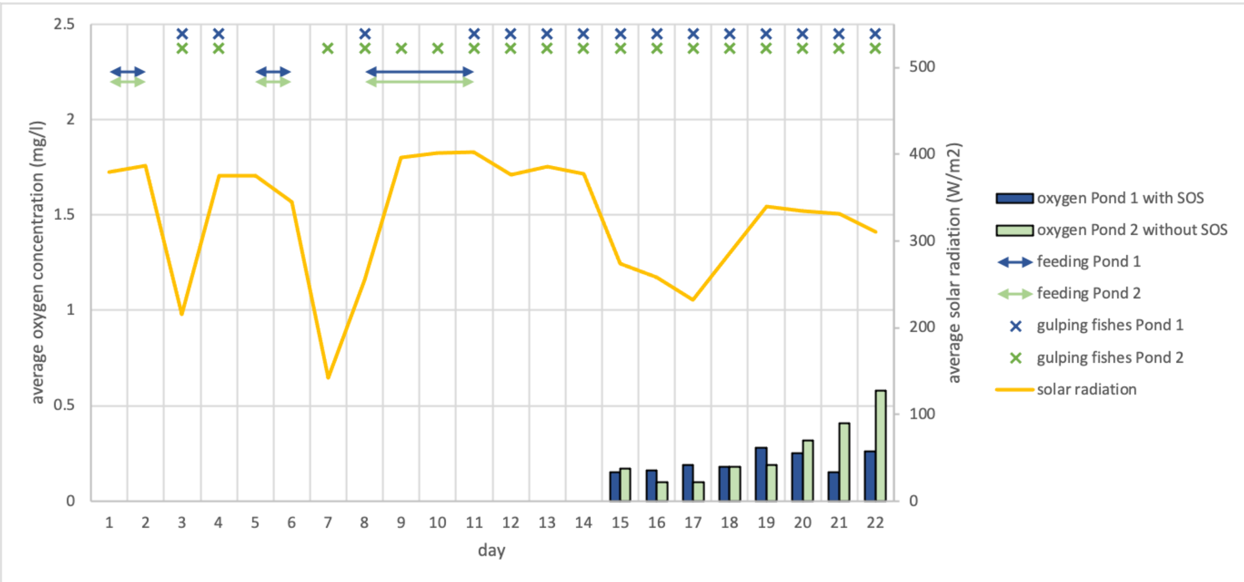

Figure 10: DO concentration Trial A every morning 06:30 (blue and green bars), solar radiation (yellow line), feeding (blue and green arrows) and fish behaviour (blue and green crosses)

The amount of food fed during experiment A can be seen in Table 3. In Pond 1 with SOS more food was fed on three days as the fishes did not gulping on day 9 and 10 (Figure 10).

Table 3: Feeding report Ponds 1 and 2 Trial A

Day	Feed intensity Pond 1	Effectively feed Pond 1	Feed intensity Pond 2	Effectively feed Pond 2
1	0.75 %	3.375 kg	0.75 %	3.375 kg
2	1.5 %	6.78 kg	1.5 %	6.78 kg
5	1 %	4.57 kg	1 %	4.57 kg
6	1 %	4.6 kg	1 %	4.6 kg
8	0.5 %	2.31 kg	0.5 %	2.31 kg
9	1 %	4.64 kg	0.5 %	2.32 kg
10	1.5 %	7.01 kg	0.5 %	2.33 kg
11	1 %	4.72 kg	0.5 %	2.34 kg
Tot.		**38.005 kg**		**28.625 kg**

The weights collected during Trial A are listed in Table 4. The sample size was increased at the start of Trial B (day 29) because the scatter of fish weights was too large to calculate an accurate average size (see discussion, Trial A).

Table 4: Average weights of the fishes from Trial A

Day	Sample size	Average weigth Pond 1 with SOS	Average weigth Pond 2 without SOS
1	50 fishes	253 g	240 g
15	50 fishes	266 g	259 g
29	200 fishes	280 g	260 g

The total daily oxygen input between 06:30 - 15:30 is shown in Figure 11. From day 20 onwards Pond 1 with SOS receives less oxygen during the day.

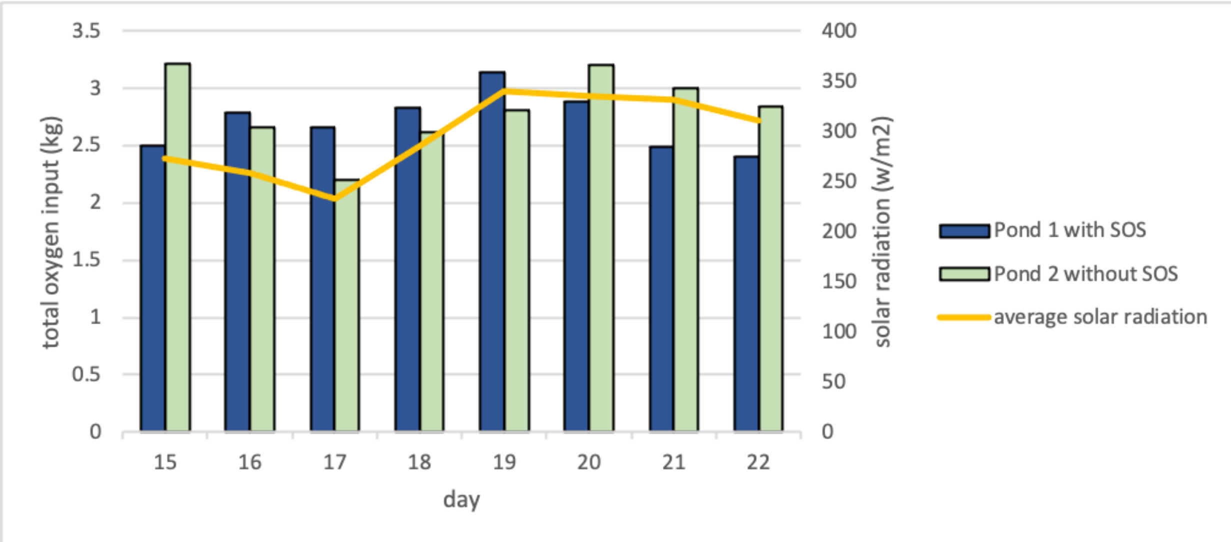

Figure 11: Total daily oxygen input (blue and green bars) and solar radiation (yellow line) Trial A

4.2 Trial B

Figure 12 shows that the morning DO concentrations in both ponds rose briefly after Trial B starts. From day 7 onwards, however, the concentrations in Pond 1 with SOS were below 0.5 mg/l daily. From this day on no more feeding took place. The DO concentrations in Pond 2 without SOS were always above 1 mg/l from day 5 onwards and rose to over 2 mg/l in some cases.

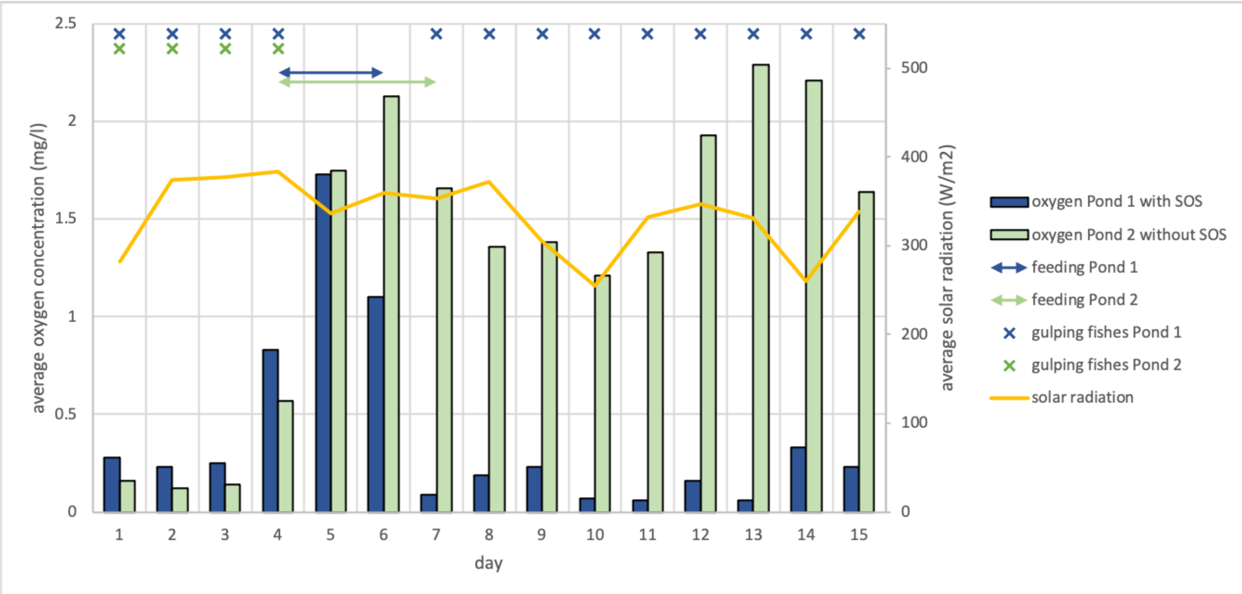

Figure 12: DO concentration Trial B every morning 06:30 (blue and green bars), solar radiation (yellow line), feeding (blue and green arrows) and fish behaviour (blue and green crosses)

The amount of feed during experiment B can be seen in Table 5. The DO concentration in Pond 1 with SOS was from day 7 onwards steadily below 1 mg/l (Figure 12). Because of that feeding was also stopped in Pond 2 without SOS from day 8 onwards.

Table 5: Feeding report report Ponds 1 and 2 Trial B

Day	Feed intensity Pond 1	Effectively feed Pond 1	Feed intensity Pond 2	Effectively feed Pond 2
4	0.5 %	1.17 kg	0.5 %	1.17 kg
5	0.5 %	1.17 kg	0.5 %	1.17 kg
6	0.5 %	1.18 kg	0.5 %	1.18 kg
7	-	-	0.5 %	1.18 kg
Tot.		**3.52 kg**		**4.7 kg**

The average weights of experiment B show a decrease of 20 g per fish in Pond 1 with SOS and an increase of 10 g per fish in Pond 2 without SOS (Table 6).

Table 6: Average weights of the fishes from Trial B

Day	Sample size	Average weigth Pond 1 with SOS	Average weigth Pond 2 without SOS
1	200 fishes	280 g	260 g
15	200 fishes	260 g	270 g

The daily oxygen input from Trial B is shown in Figure 13. In the pond equipped with an SOS, the total input is below the input calculated for the pond without SOS only from day 8 to day 10.

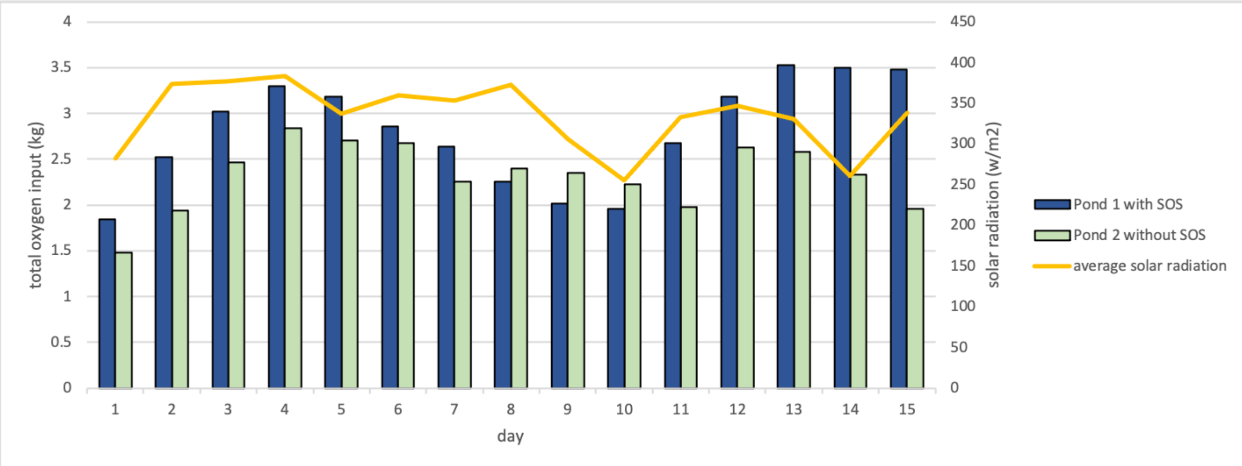

Figure 13: Total daily oxygen input (blue and green bars) and solar radiation (yellow line) Trial B

A boxplot (Figure 14) of the daily oxygen input shows that during the two weeks of Trial B, on average 0.48 kg more oxygen was enriched in the pond water in the Pond 1 with SOS than in the Pond 2 without SOS.

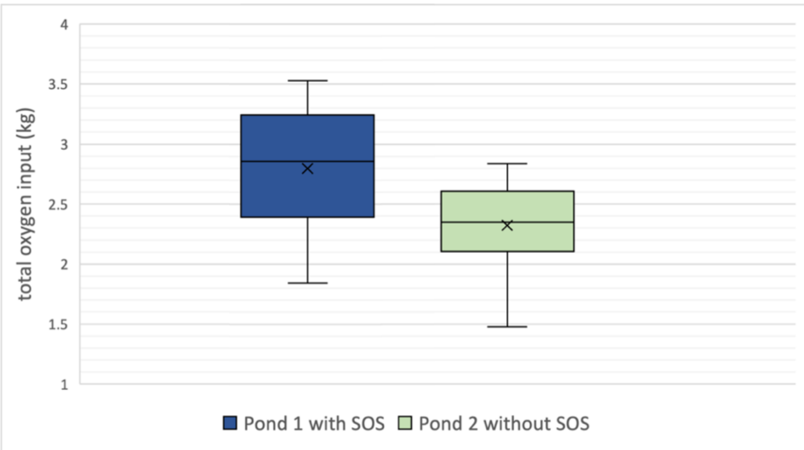

Figure 14: Boxplot daily oxygen inputs Trial B from 06:30-15:30

Figure 15 shows the change in DO concentration during the day in four different water depths. After the start of Trial B, the morning concentrations are below 1 mg/l in both ponds. From day 6 onwards, there is more oxygen in the Pond 2 without SOS in the morning. At dusk at 17:30 the DO concentrations in all depths in Pond 1 with SOS are close together while in Pond 2 without SOS a stratification is clearly visible.

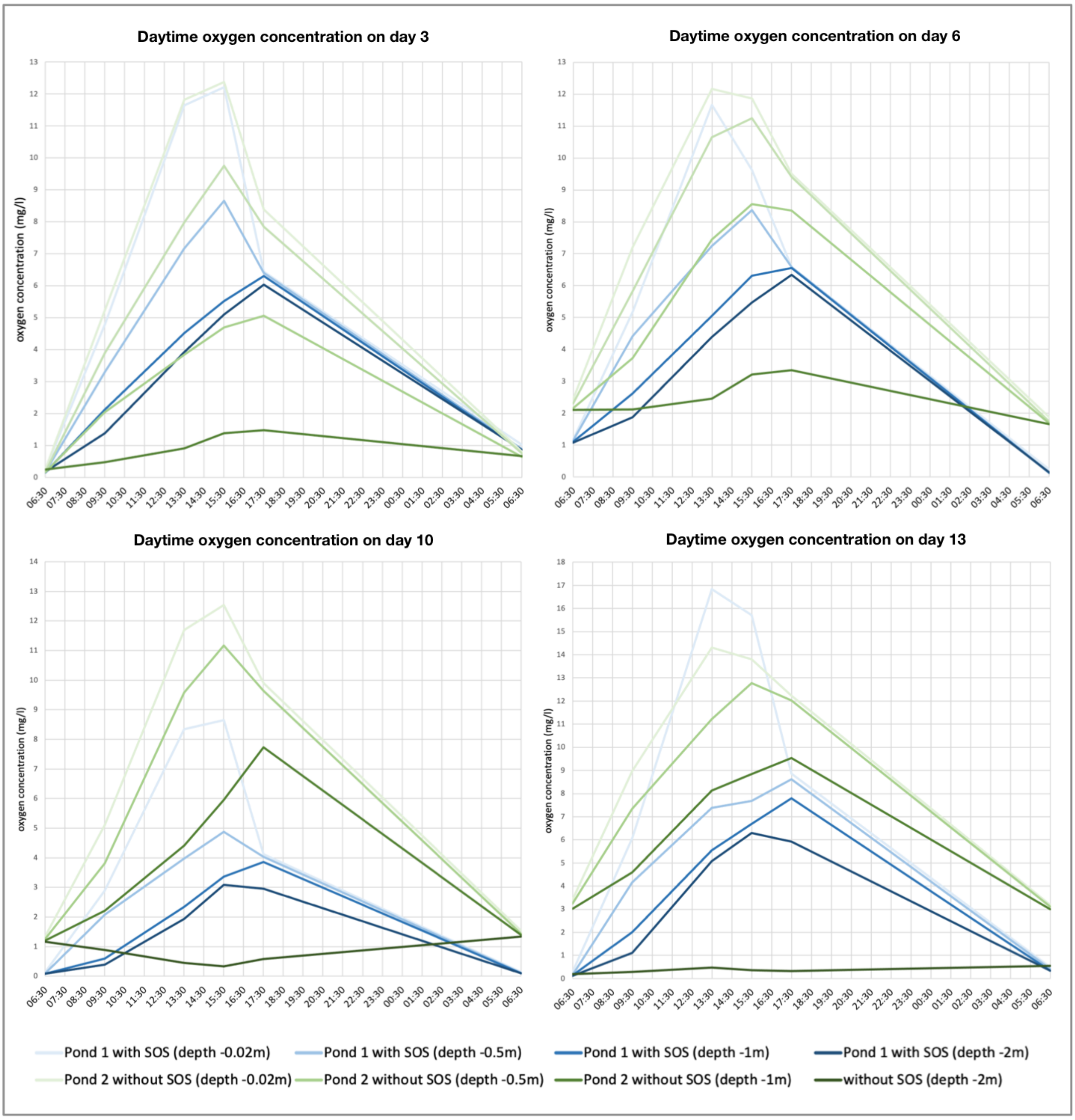

Figure 15: Daily curve of DO concentration in different depths from Pond 1 (blue lines) and Pond 2 (green lines)

4.3 Water quality parameter Trial A and B

The water quality parameters measured weekly are shown in Figure 16 and Figure 17.

During the test period, conductivity, temperature and nitrites changed in the same way in both ponds and showed very similar values. Conductivity increased slightly during the experiment (Figure 16). The temperature fluctuated between 28.5 and 31.7 C° and decreased over time (Figure 16). The measured turbidity was initially the same in both ponds, but developed differently in the ponds over time. Turbidity rose sharply in Pond 1 with SOS up to day 22 (Trial A) and then fell again towards the end of Trial B. In Pond 2 without SOS, turbidity was even lower on days 15 and 22 (Trial A) and only reached its maximum towards the end of Trial B. If the turbidity is higher in one pond, the COD concentration is also higher than in the other pond (Figure 16).

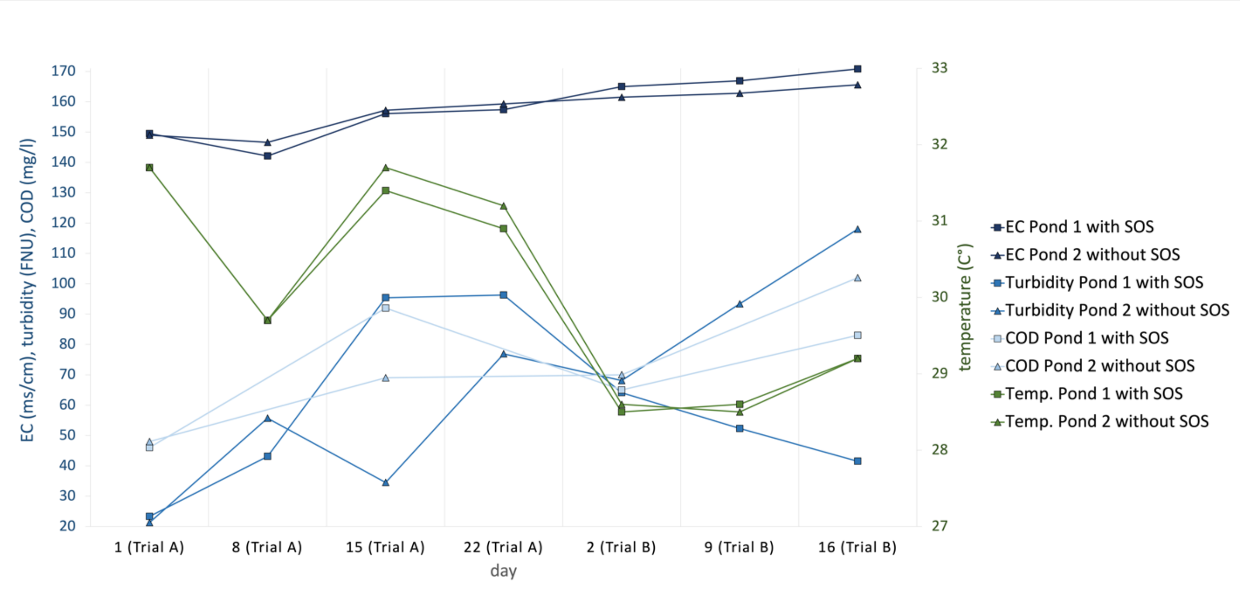

Figure 16: Water chemistry measurements Trial A and B; conductivity (dark blue), turbidity (blue), COD (clear blue), temperature (green)

Phosphate-phosphorus increased slightly during the experiment and is always higher in the Pond 1 with SOS (Figure 17). The pH values of the two ponds ranged between 8.42 and 9.3. From day 15 the pH value was higher in the Pond 2 without SOS (Figure 17). The nitrite-nitrogen concentration changed parallel to each other in both ponds and was slightly higher at the start of the experiment but was always below 0.26 mg/l thereafter (Figure 17). The nitrate-nitrogen concentration was only collected for Trial B. It was only higher at the beginning of the trial in the Pond 1 with SOS (Figure 17). The total ammonia nitrogen (TAN-N) is below 0.22 mg/l in both ponds during Trial A, but then rises above 1.2 mg/l in both ponds until the end of Trial B (Figure 17).

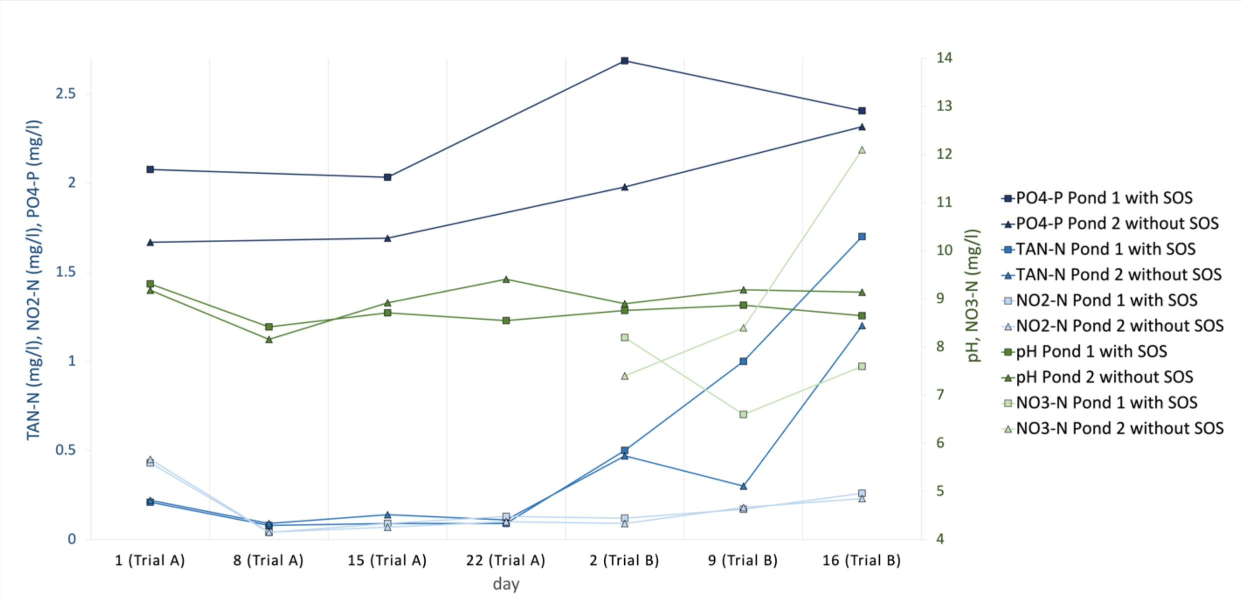

Figure 17: Water chemistry measurements Trial A and B; PO4-P (dark blue), pH (dark green), NO_3-N (clear green), TAN-N (blue), NO_2-N (clear blue)

4.4 SOS performance

Figure 18 shows how many watts were produced by the solar panel under sunny and cloudy skies and how much was consumed by the running SOS.

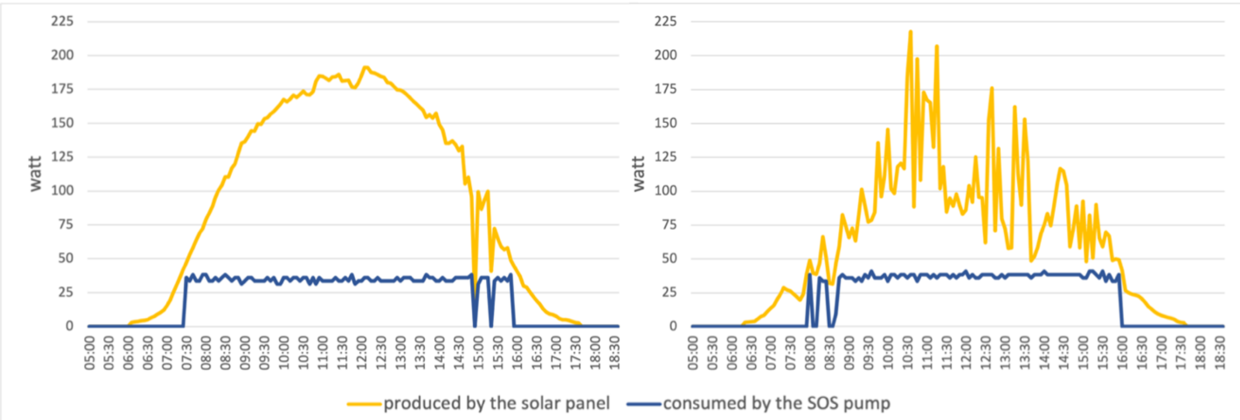

Figure 18: Produced Watt by solar panel (yellow) and consumed Watt by SOS pump (blue); comparison a sunny (left) with a cloudy day (right)

Table 7 shows the total energy produced and consumed by the solar panel and SOS pump on the same days like Figure 18 as well as the energy surplus that could be available in addition.

Table 7: Total of produced and consumed energy

Weather	Produced energy solar panel	Consumed energy SOS pump	Surplus energy
sunny	1.15 kWh	0.29 kWh	0.86 kWh
cloudy	0.71 kWh	0.28 kWh	0.43 kWh

A comparison of the SOS runtime at different pump speed settings is shown in Figure 19. On a rainy day during the rainy season, the SOS pump at level 5 would be in operation for 2.1 hours longer (Table 8). This is more than one third of the total runtime. In good weather, the daily pump operation at level 5 is only extended by 30 minutes.

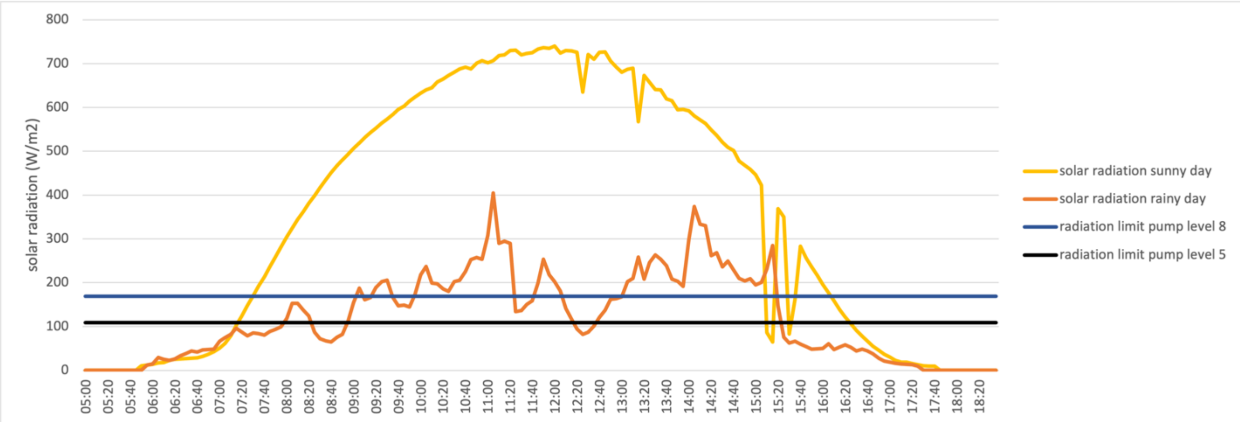

Figure 19: Comparison of the solar radiation on a sunny day (yellow) and a rainy day (orange) with the radiation limit for pump level 5 (black) and level 8 (blue)

Table 8: Running time pump level 5 and 8

Level pump controller	Minimum solar radiation	Running time sunny day	Running time rainy day
level 8	169 W/m^2	8.3 h	4.5 h
level 5	109 W/m^2	8.8 h	6.6 h

5 Discussion

Based on literature, the discussion and explanation of the results obtained follows. Further ideas and recommendations for future SOS tests are also discussed.

5.1 Trial A

The DO concentrations in both ponds reached a low level very quickly in experiment A and fell below 1 mg/l. This was easily recognisable by the fact that the fishes gulping as early as the third day. At the start of the experiment, it can be seen that fish gulping less on sunny days with higher solar irradiation as more oxygen is introduced into the water through photosynthesis.
Figure 16 shows a increase in turbidity within one week. Increased turbidity is usually caused by increased algae growth. Reasons for increased algal growth may include rising water temperatures (Boyd and Tucker 1998). A comparison of the measured water temperatures of Trial A showed that the temperatures at 0.5 m depth at 15:30 in Pond 1 and 2 were on average 1.28 C° higher than in the neighbouring tilapia farm from where the pond water originated. On one hand this can be explained by the fact that the much smaller water body of the experimental ponds warms up faster during the day. On the other hand such a temperature increase in the pond water could also be caused by the black pond liner that was installed in the ponds, as it absorbs a lot of sunlight. George, Albert, and James (2018) show that ponds lined with pond liner warm up faster and have lower DO concentrations due to the higher water temperatures. The high phytoplankton concentration in the water due to such an algal bloom leads to an additional oxygen sink overnight.
Another oxygen sink in the SOS pond could have been caused by the stirring up of sedimented material since the water used for the experiment was already rich in phytoplankton and nutrients. In addition, it is conceivable that sedimented material in the form of mud was transported by the submersible pump when filling the ponds. Although a lot of oxygen was dissolved in the water by the algae during the day, the concentration did not rise above 0.5 mg/l in the morning. Therefore, experiment A was terminated and the fish density in the ponds was halved.
Contrary to the assumption that the SOS leads to a better DO concentration in deeper water layers Figure 11 shows that the total input of oxygen between 06:30 and 16:30 was lower the last three days in Pond 1 with SOS. One reason for this could be a blocked SOS pipe. At the end of experiment A and a check of the SOS, a piece of the pond liner was found in the pump motor (Figure 20). Since the installed data loggers only check the current flow and this is guaranteed even when the motor is not rotating, this problem was not detected earlier.

Figure 20: Piece of pond liner wich clogged the SOS pump

Weighing the fish every fortnight showed a greater growth of fish in the Pond 2 without SOS by 6 g between day 1 and day 15 (Table 4). The fact that 9.38 kg more was fed in Pond 1 with SOS in this time indicates that the sample size was too small. Figure 21 shows a high dispersion of the fish weights. The average standard deviation of all weights is 43.95 g. For these reasons, the sample size for Trial B was increased from 50 to 200.

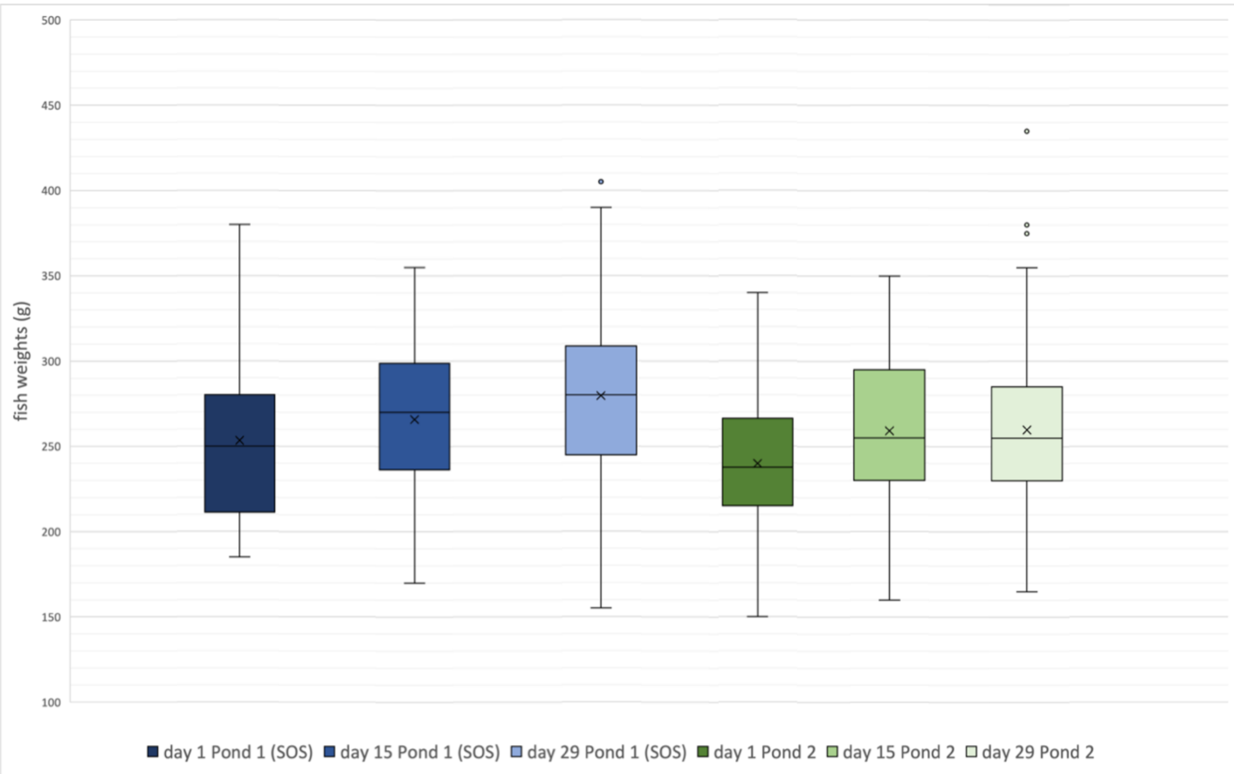

Figure 21: Boxplot of the distribution of fish weights from Trial A

5.2 Trial B

The morning DO concentration in the ponds rose above 1 mg/l within 5 days after halving the fish density. After three days of feeding, the DO concentration in Pond 1 with SOS dropped to below 0.5 mg/l on the seventh day and remained this low until the end of the trial. This was also observed in the fish behaviour by gulping. In Pond 2 without SOS the DO concentration always remained above 1 mg/l in the morning. Here too it can be assumed that the oxygen-consuming substances such as dead phytoplankton, sediments and fish faeces were kept in suspension by the water circulation of the SOS and thus led to a reduction in the DO concentration during Trial B. This hypothesis is supported by the fact that in Pond 2 without SOS, a stratification with different DO concentrations was evident (Figure 15). At 2 m depth, the DO concentration in Pond 2 without SOS was always very low. On day 13 it can be seen that it was very close to 0 mg/l throughout the day. This is an indication that oxygen-consuming substances sediment and accumulate at the bottom of the pond. Such an anaerobic layer could not form in Pond 1 with SOS. Figure 15 clearly shows that the pond water is well mixed at 17:30 and a uniform DO concentration is found at all water depths. The good mixing of the pond water by the SOS can also be shown by the water temperatures measured daily. A comparison of the two ponds shows that the temperature difference at 15:30 between surface water and pond bottom was much higher in Pond 2 without SOS during the test period (Figure 22).

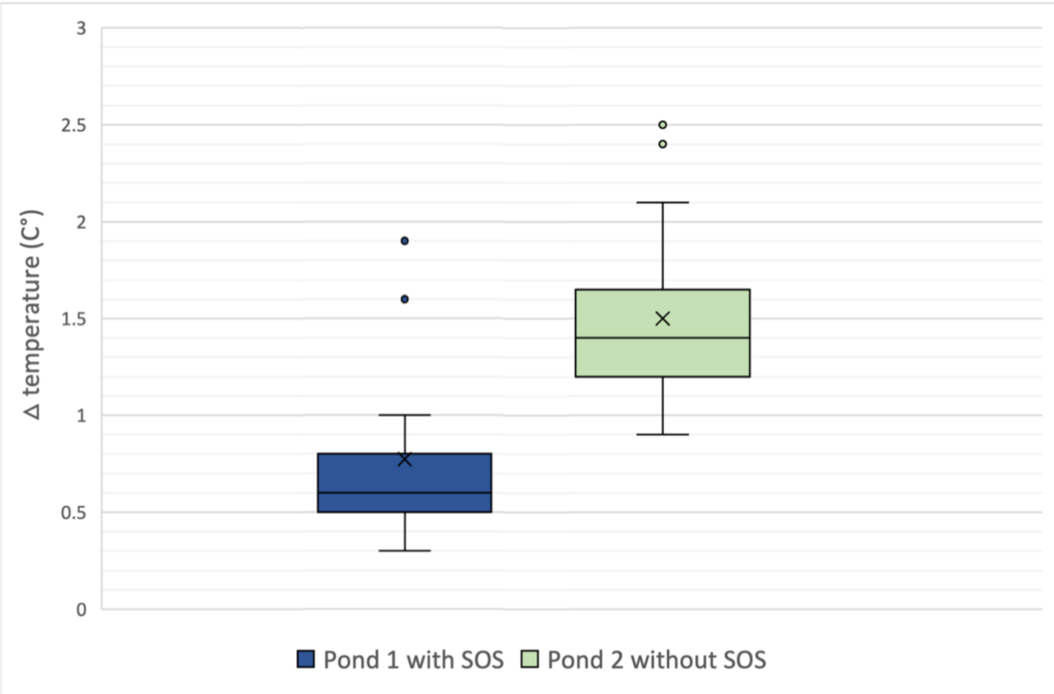

Figure 22: Boxplot of the temperature delta between water surface and -2m depth at 15:30

During Trial B, higher TAN-N values were measured in Pond 1 with SOS. This could also be related to better mixing of the water. Sriyasak et al. (2015) showed that TAN-N concentrations in various fish farm ponds in Thailand are lower in the surface water than at the bottom of the ponds. Therefore, after destratification of the water, elevated TAN-N levels were found.

Based on the TAN-N, the water temperature and the current pH value, the current ammonia content in the water can also be calculated (Florida Department of Environmental Protection 2001).

Ammonia is one of the most important water quality parameters in aquaculture as it has a toxic effect on fish in low concentrations (Boyd and Tucker 1998). The proportion of ammonia nitrogen (NH_3-N) in TAN-N can be determined with the help of pH/temperature tables (Appendix D). The measured maximum TAN-N value was recorded on day 16 (Figure 17). Using the measured temperature of 29.2 C° and the pH values 8.65 in Pond 1 with SOS and 9.14 in Pond 2 without SOS, ammonia nitrogen concentrations of 0.43 mg NH_3-N/l in Pond 1 with SOS and 0.62 mg NH_3-N/l in Pond 2 without SOS were obtained. These values are rather high if one considers that the short-term LC50 values for fish at a pH above 7 for NH_3-N are between 0.5-3 mg/l and the long-term LC50 values are between 0.05 - 0.2 mg/l (Boyd and Tucker 1998).

Another reason for a difference in DO concentrations between the two ponds could be a non-synchronous algal bloom. The turbidity over the entire test period shows different trends in the two ponds. It can be assumed that an algal bloom started earlier in Pond 1 with SOS. Turbidity rose sharply until day 22 of Trial A and then fell again. While in Pond 2 without SOS the strongest increase can only be seen towards the end of the trial. Such an offset algal bloom could also be observed in the colour of the pond water. Figure 23 shows from the pond water colour that the stronger algal growth was found in Pond 1 with SOS on day 10 of Trial A while an algal bloom was observed in Pond 2 without SOS on day 8 of Trial B. This also correlates with the measured turbidity. Such strong differences in the phytoplankton composition make a concrete statement about the efficiency of an SOS rather difficult. The efficiency of the SOS is directly related to the photosynthesis-induced oxygen production of the algae. For a further experiment, it is therefore highly recommended to use more than two experimental ponds so that the relationship between algal blooms and SOS can be better understood. For the same reasons, it is recommended to start the experiment with lower nutrient water. Firstly, the SOS benefit can be better investigated and the nocturnal oxygen depletion by phytoplankton would be kept to a minimum.

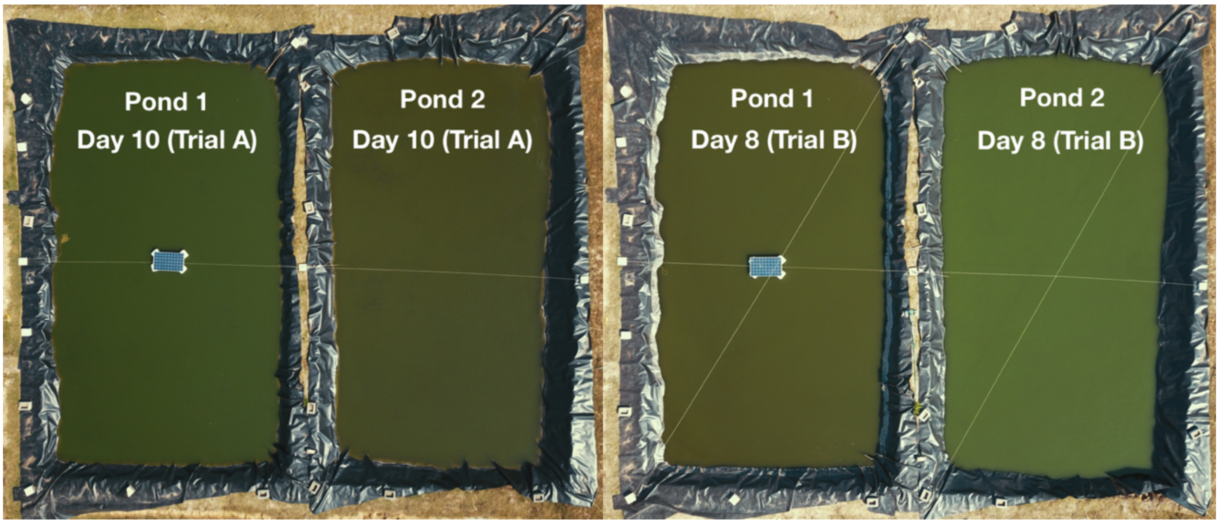

Figure 23: Comparison water color of the fish ponds on day 10 of Trial A and day 8 of Trial B

Monitoring of the water quality parameters show a slight increase in phosphate phosphorus during the trial period. The slight phosphate input can be explained by the added fish feed although feeding was very sparse during the trial. Another source of phosphate could be nutrients carried by wind. During the trial period, windy conditions often prevailed and organic material was found on the water surface.

In the pond with the higher turbidity there is usually also a higher COD concentration. But there was not a clear correlation between the turbidity and the COD concentration per pond. Literature shows that the correlation between turbidity and COD is not always high and always site specific (Tommassen 2014).

The measured nitrite values were low over the entire test period, while the nitrate values increased significantly with increasing TAN-N. One explanation for this is that nitrite does not accumulate in the environment and normally converts to nitrate as quickly as it is produced during nitrification (Boyd and Tucker 1998).

Over the experimental period, fish in Pond 2 without SOS grew on average 10 g per head while in Pond 1 with SOS they became 20 g lighter. Since only 3.52 kg and 4.7 kg respectively were fed over a period of 2 weeks, a decrease in fish weights is very plausible. However, it is not entirely clear why such a large difference was found between the ponds. It has been proven that low DO concentrations have a significant negative effect on fish growth (Abdel-Tawwab et al. 2015). Although there was less oxygen in Pond 1 with SOS for a longer period of time, the difference in fish weights cannot be explained by this. The difference in weight is too great and the duration of the experiment too short. It is much more likely that the sample size of 200 individuals is still too small to calculate a representative average weight due to the high standard deviation Figure 21.

5.3 Oxygen measurement

To estimate the precision of the calculated oxygen inputs over the day (Figure 11 and Figure 13), a height profile of the ponds was also created and the DO concentration was measured every 5 cm. The resulting curve was compared with the interpolated values of the four measurement heights chosen for the calculations. Figure 24 shows a good correlation between the measured and interpolated values.

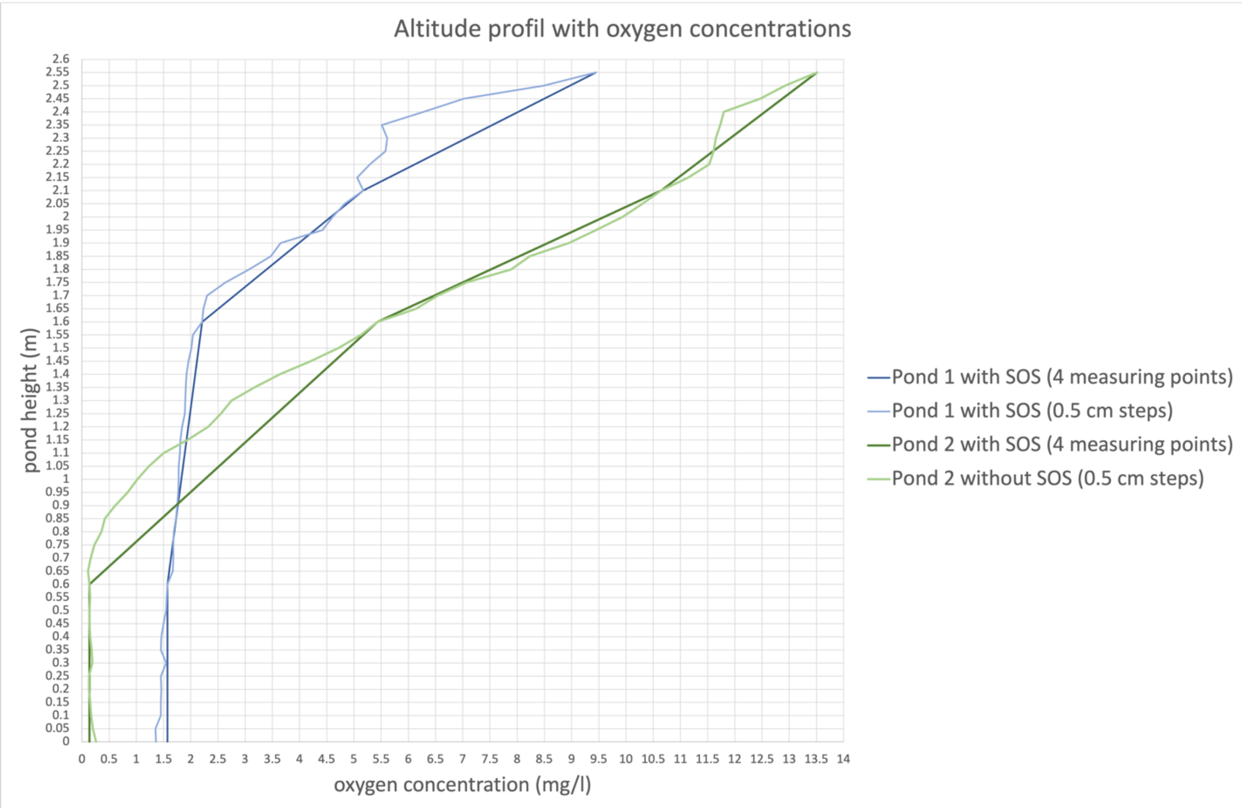

Figure 24: Altitude profile of measured (clear colours) and interpolated (dark colours) DO concentrations

If the total DO content in the ponds is calculated and compared with the existing measured values, the result of the interpolated values is about 0.16 kg O_2 higher. To obtain a more accurate estimate of the total oxygen in the ponds, two more measuring heights could be sampled in a further experiment. If the DO content were additionally measured at a depth of 25 and 150 cm, the total DO content of the existing interpolated values would only be 0.05 kg O_2 higher than that of all measured values.

5.4 SOS performance

The comparison in Table 7 shows that in good weather the surplus energy produced by the solar panel of 0.86 kWh is twice as high as on a cloudy day. It is conceivable to use this surplus energy for other applications. For example, charging a mobile phone or laptop. However, it must be taken into account that additional power consumption can also affect the performance of the SOS. For example, the SOS would operate for less time when charging a mobile phone in the morning and in the evening, as the solar panel may not produce enough power for both consumers during these times. This depends very much on how much additional wattage is being consumed. For example, if an iPhone 11 is charged with a 20 Watt adapter in the morning hours, the SOS pump will start about 10 minutes later, provided the weather conditions are good. This is not very significant for a mobile phone, but if a laptop is charged with a 96 Watt adapter, for example, the start time of the SOS is delayed by more than an hour. In bad weather, this will considerably reduce the total runtime. It is therefore recommended to use the surplus power during the midday hours. It is also possible that a technical solution is conceivable here that prioritises the power consumption for the SOS pump, so that this problem can be circumvented. In the case of additional electricity consumers, however, further measurements should be carried out first. The underlying power curve of the solar panel is only intended as an approximation. According to Christen (2020), the linear power decrease of the panel, which was assumed for this work, is no longer guaranteed below 300 W/m^2.

In Figure 19 it was shown that the runtime of the SOS can be extended considerably during rainy days if the speed at the pump controller is reduced. However, this also reduces the performance of the SOS. To ensure an optimal yield of runtime and water flow, flow measurement of the different speed levels would be necessary. A more elegant solution would be a stepless pump motor that adjusts the speed to the available energy. The trial also showed further possibilities for improvement of the Sun Oxygen system. It was noticed that the step-down module used gets very hot. However, overheating was not observed. In view of the coming dry season with air temperatures of up to 40 C°, it is recommended to observe the heat development of the step-down module more closely (Wetter & Klima in Kambodscha: Klimatabelle).

As the surface of the solar panel gets dusty very quickly due to a lot of sand in the air, it is recommended to clean the panel regularly to avoid performance losses. Rahman et al. (2012) showed that accumulated dust on the surface of a solar panel in Bangladesh can reduce its performance by up to 35% within a month. However, as the pump motor of the SOS only needs about one third of the produced energy of the solar panel on nice days, such a high power drop will not occur. A short test on site with a solar panel that had been dusty for 2 weeks showed that the SOS pump starts 14 minutes later in the morning with the dusty panel. This can lead to a shorter runtime of the SOS, especially in cloudy weather. Further tests could show the extent of the loss of performance after a longer period of time, for example 3 months. This could be an important point in the creation of a maintenance or cleaning plan for the SOS. Perhaps a slightly slanted solar panel on the SOS would prevent dusting better. Especially during the rainy season, the layer would be washed off by the rain. Another idea is to use the excess energy produced by the solar panel with a timer and another small water pump to clean the panel automatically on a regular basis.

To reduce the possible stirring up of oxygen-consuming sediment, it is recommended to close the pipe of the SOS pump at the bottom. The water mixing would still be ensured by lateral outlets.

Another conceivable possibility would be to shorten the pipe so that the pump of the SOS stirs up less sediment at the bottom and sedimentation in the pond remains guaranteed. Further tests with different SOS variants could show which design would provide the greatest possible benefit.

Another idea to reduce oxygen depletion is the active removal of sediment and sludge that accumulates at the bottom of fish ponds. Reiter, Sindilariu, and Wedekind (2008) showed that the removal of solids with the help of a sedimentation tank can significantly reduce the nutrient load as well as the chemical oxygen demand in the effluent water. A favourable variant of a sedimentation tank could be a self-built swirl filter (Figure 25). Such sedimentation tanks are used in aquaponic or biofloc systems (Janis 2019). They work on the principle that heavy solids in the water fall to the bottom through a circular flow at the side of a round basin and the clean water can be collected again in the middle of the basin (Figure 25).

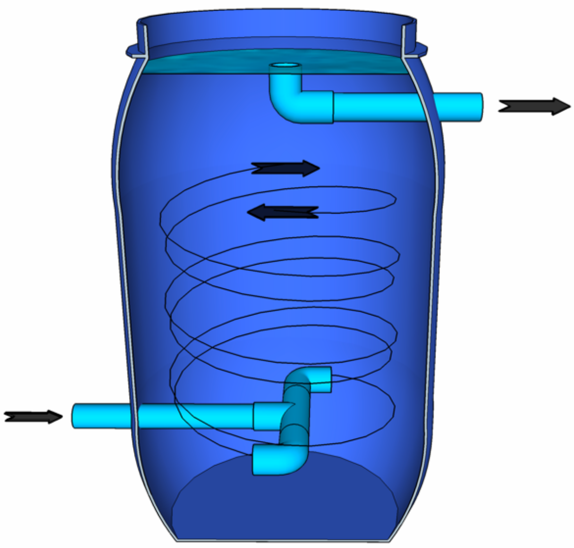

Figure 25: Possible low-cost variant of a self-built Swirl Filter. Groundwater from the pond flows into the filter in the lower part, the rotation causes the sediments on the barrel wall to sink and the purified water can be collected again at the top centre.

A design modification of the SOS could thus suck water and sediments from the bottom of the pond and pump them into the sedimentation basin where the sediments could be removed from time to time. The sludge from the sedimentation basin could in turn be used as fertiliser in the surrounding agriculture.

The extent to which the water circulation and thus the distribution of the oxygen-rich surface water in the entire pond is maintained by the outflow and the suction at the bottom of the pond would first have to be tested. It would also have to be considered whether the SOS should be moved from time to time in the pond so that the sediments can be removed from the entire pond bottom.

5.5 Aerator performance test (SOTR / SAE)

Since aeration tests are carried out in clean and nutrient-poor tap water, a direct comparison of the aeration performance of the SOS on site is not possible. Boyd (Boyd 1998) advises against aeration tests in ponds with high nutrient loads or high phytoplankton abundance as additional oxygen is input and consumed by photosynthesis and respiration. The daily oxygen input in this work was calculated from 06:30-15:30. However, the SOS only ran for 7.6 h on average over all days. It can also be assumed that algal blooms in the ponds occur at different times. These are further factors that contradict a direct comparison with other SOTR/SAE values.

Nevertheless, as an approximation, the theoretical SOTR and SAE values of the SOS are briefly calculated here. However, it must be explicitly pointed out that the calculations are not correct and are not based on standard conditions of an aeration performance test.

In the Pond 1 with SOS, the average daily oxygen input during Trial B was 0.48 kg higher than in the Pond 2 without SOS. The SOS ran for an average of 7.6 hours and the pump consumed an average of 36.3 watts. This corresponds to a daily power consumption of 0.28 kWh. From this, a SOTR value of 0.06 kg O_2/h and a SAE value of 1.7 kg O_2/kWh can be calculated.

Table 9 shows SOTR and SAE values of different tested ventilation systems (Boyd 1998).

Table 9: Different SOTR (kg O_2/h) and SAE (kg O_2/kWh) values of different aeration systems

Type of aerator	Number of aerator	SOTR (range)	SAE average	SAE (range)
paddle wheel	24	2.5 - 23.2	2.2	1.1 - 3.0
propeller-aspirator-pump	11	0.1 - 24.4	1.6	1.3 - 1.8
vertical pump	15	0.3 - 10.9	1.4	0.7 - 1.8
pump sprayer	3	11.9 - 14.5	1.3	0.9 - 1.9
diffused-air	5	0.6 - 3.9	0.9	0.7 - 1.2
SOS	1	0.06	1.7	1.7

A SOTR of 0.06 kg O_2/h is very low, but on the other hand the energy efficiency of the SOS is high at 1.7 kg O_2/kWh. It is also conceivable that the theoretical oxygen input and thus the SOTR values are higher, since the SOS swirls up more oxygen-consuming sediment.

6 Conclusion

Unfortunately, the present test with the Sun Oxygen System could not yet provide clear data on the basis of which an added value for the SOS can be quantified. However, it showed various difficulties and possible improvements. An adjustment of the SOS pump tube should prevent the swirling up of sediment in a further test. Filling the ponds with clean groundwater at the start would also prevent too high an oxygen sink due to phytoplankton. The systems would also be more comparable, as the strong fluctuations within the phytoplankton community would be smaller at the beginning.

Tests with different design adaptations would also be conceivable. For example, a closed pump tube with lateral outlets or a shortening of the tube to 50 cm. First and foremost, the performance of the SOS should be investigated. Possibly, another experiment without fish would also be interesting for this purpose, which could show the differences in oxygen distribution in an experimental pond. In experiments with fish, the focus should be on a uniform fish size. This can reduce errors in the growth curve due to a too high standard deviation. This would also be very important for accurate feed management. The FCR is used to determine the daily feed quantity, which can only be accurately determined with exact growth figures.

Furthermore, it would be interesting to better control the reproduction of the tilapias in a future trial. After the end of the trials, a lot of juveniles were found in the ponds. How high their biomass was and what this means for further oxygen consumption was not investigated. This would require fishing with a small-mesh trawl net.

For further trials or future use of the SOS in the Woman in Aquaculture Project, cleaning of the system and waste management around the fish pond should also be considered. Contamination of the solar panel, as well as clogging of the SOS pump, can lead to major performance losses. A polluted environment due to PET bottles, pond foil remnants and other materials after the construction of new fishponds has often been observed. This problem should be addressed when training future fish farmers, as well as security measures for children and animals because of the slivery pond liner.

For a better understanding of the oxygen balance in fish ponds, further scientific investigations in the field would also be useful. For example, the phytoplankton communities and the changes in their composition over time could be better investigated by ZHAW students. This could bring added value for the targeted use of an SOS.

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Directory of images

Directory of Tables

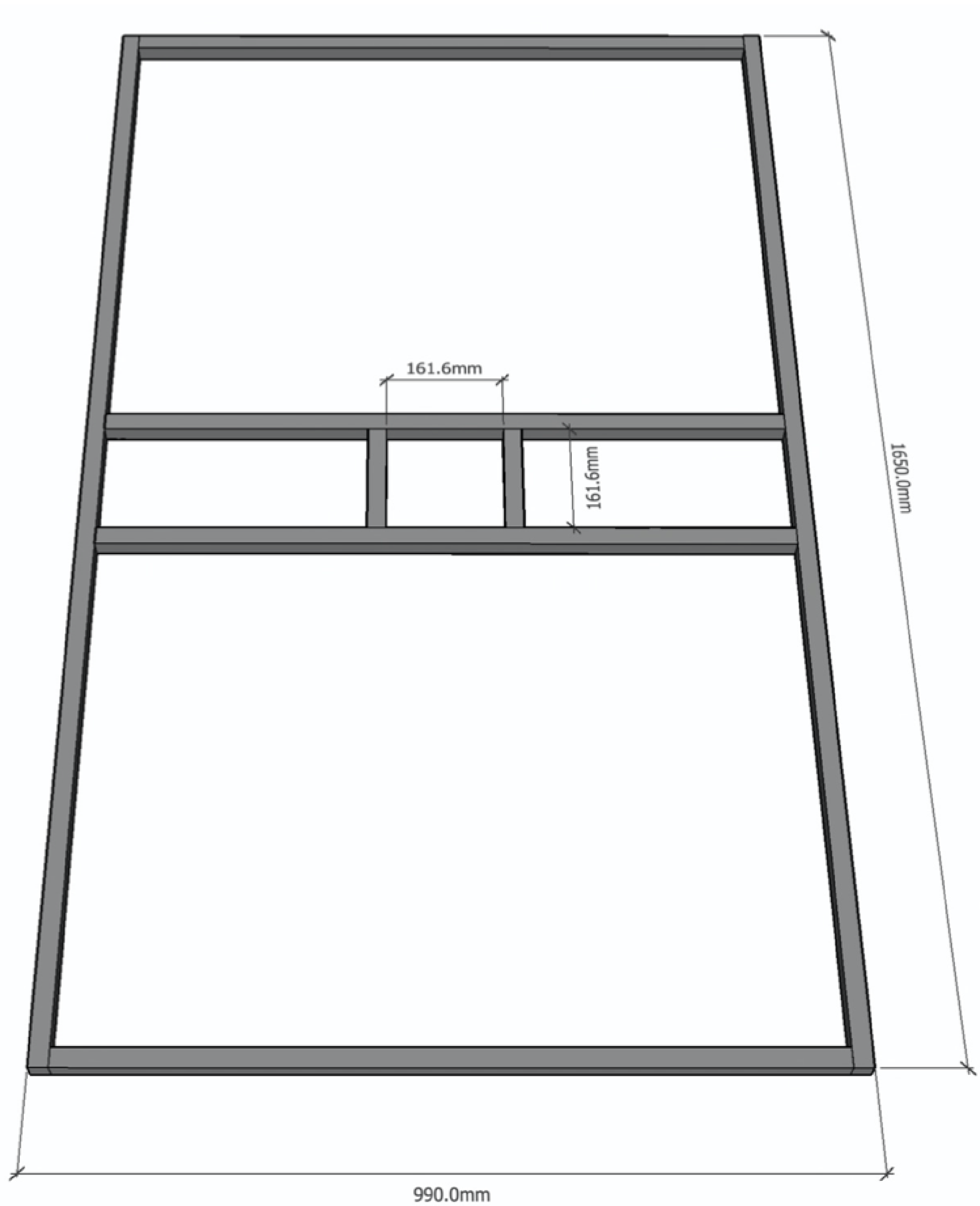
Appendix

Appendix A

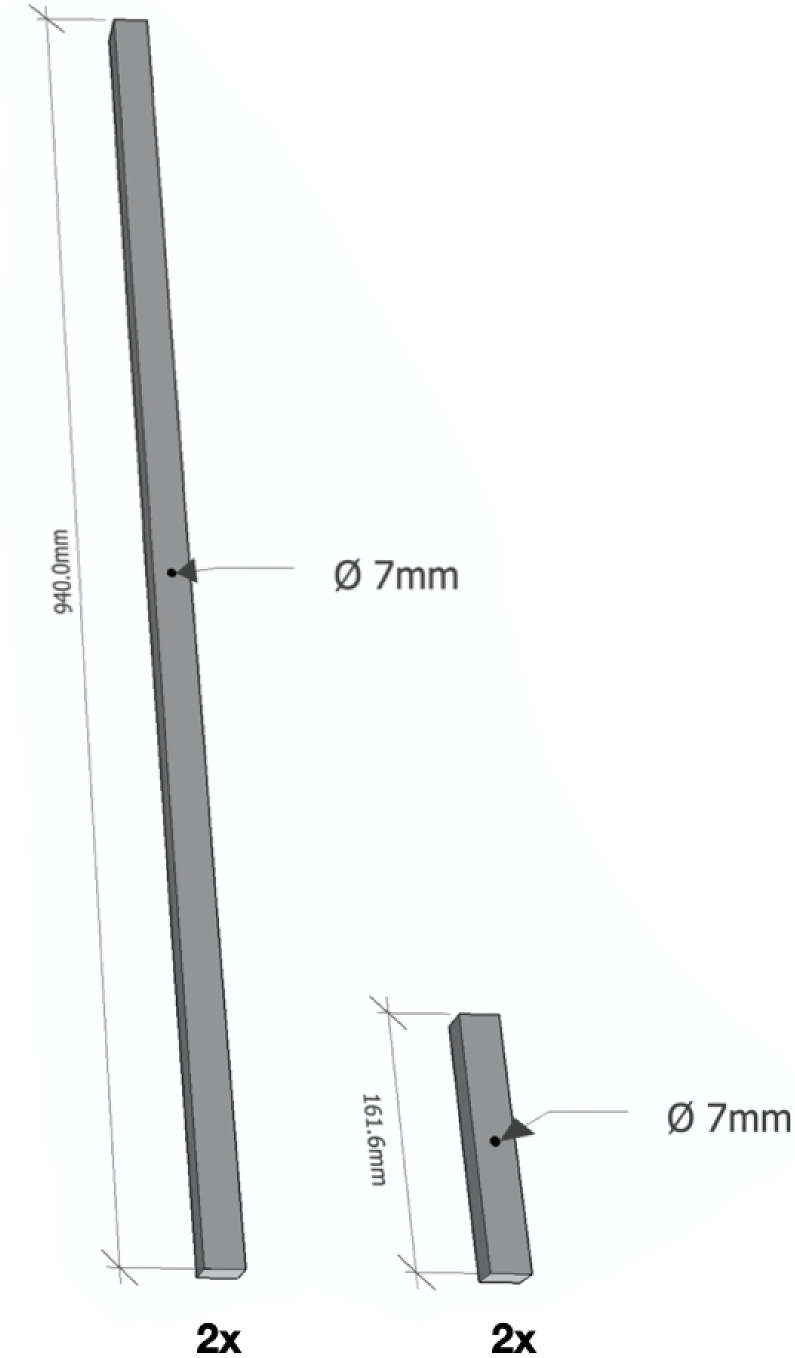
Sun Oxygen System (metal)

construction manual

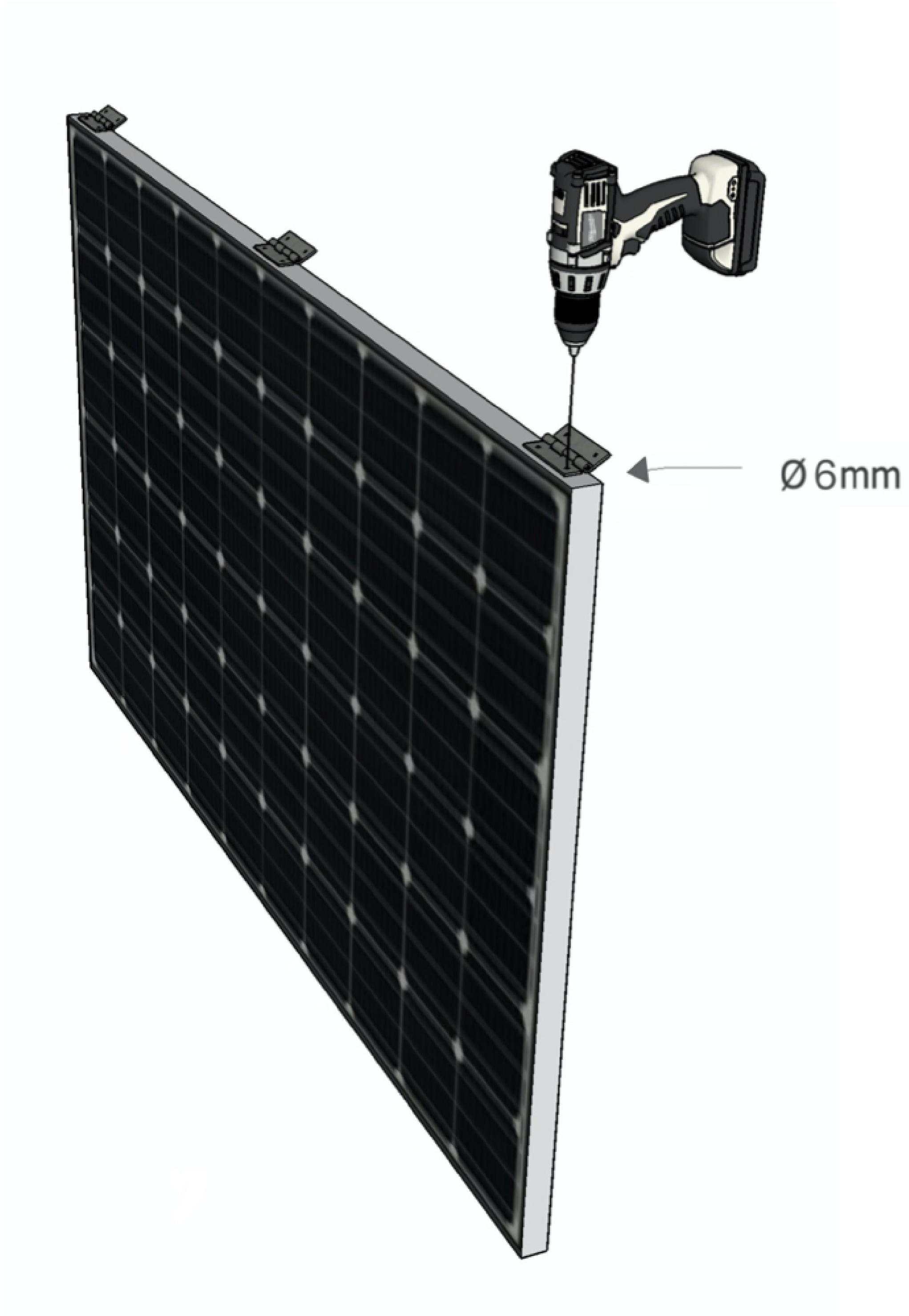
Dimensions



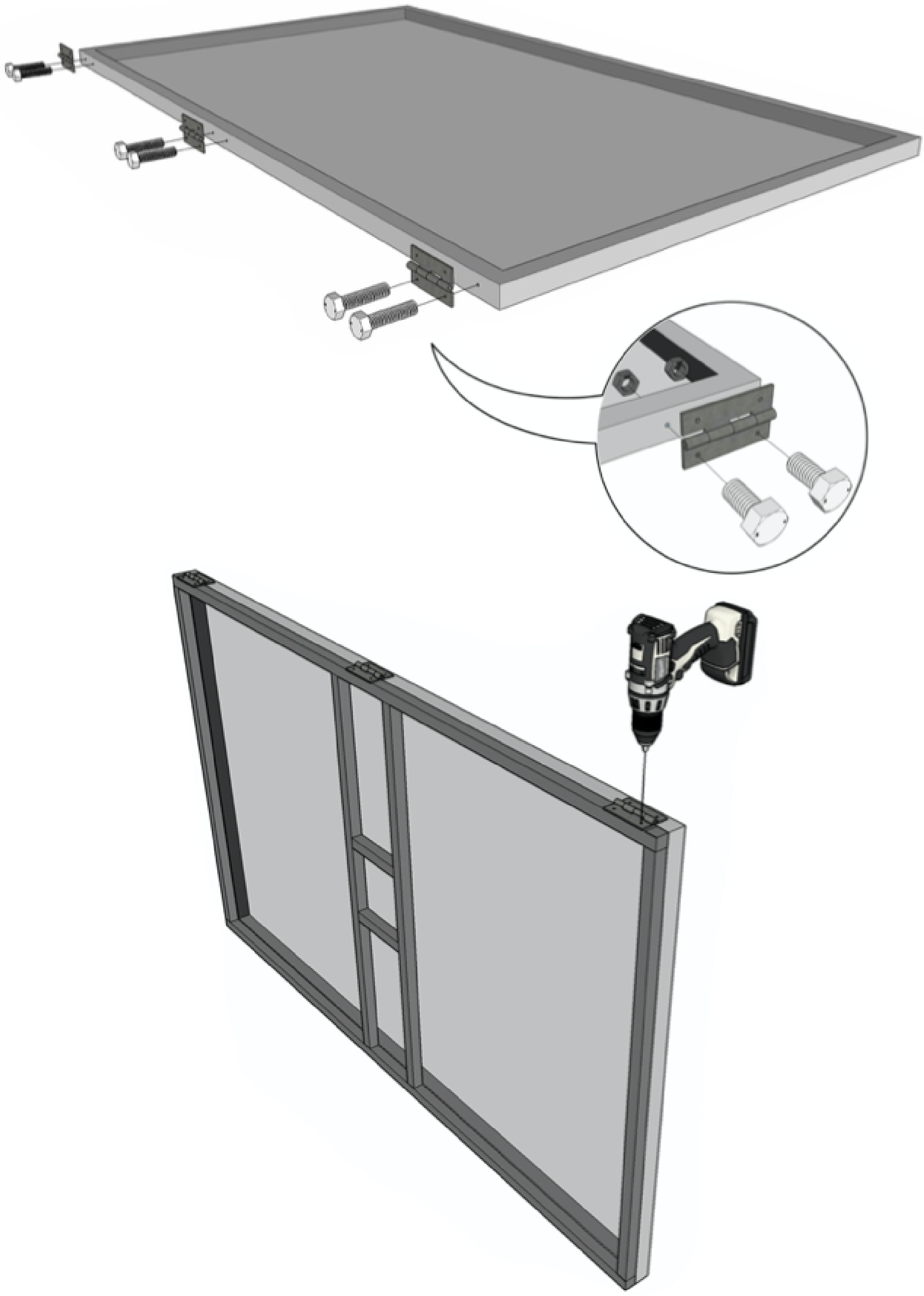
Drilling



The 7mm holes are in the middle of the metal rods.

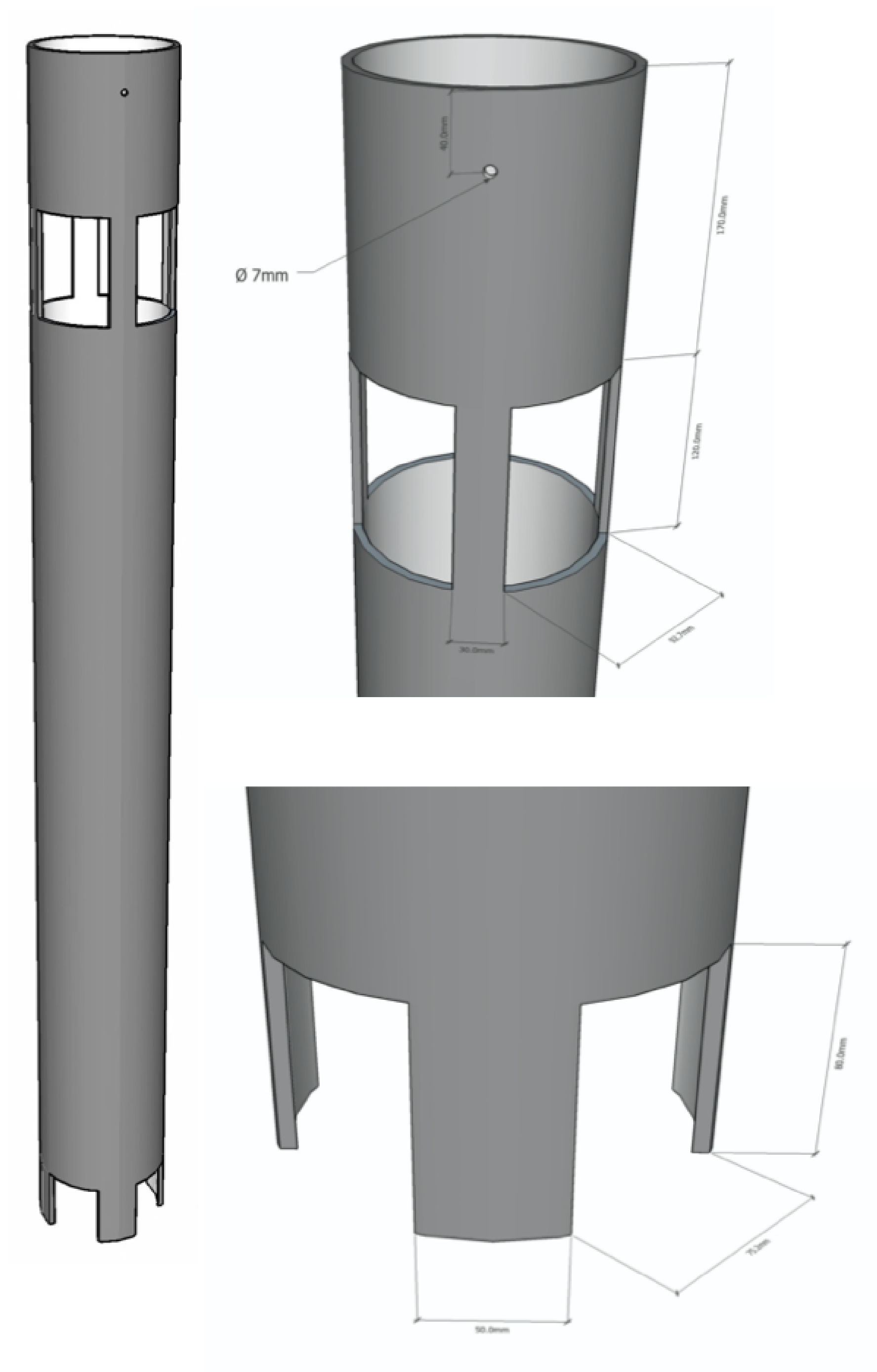


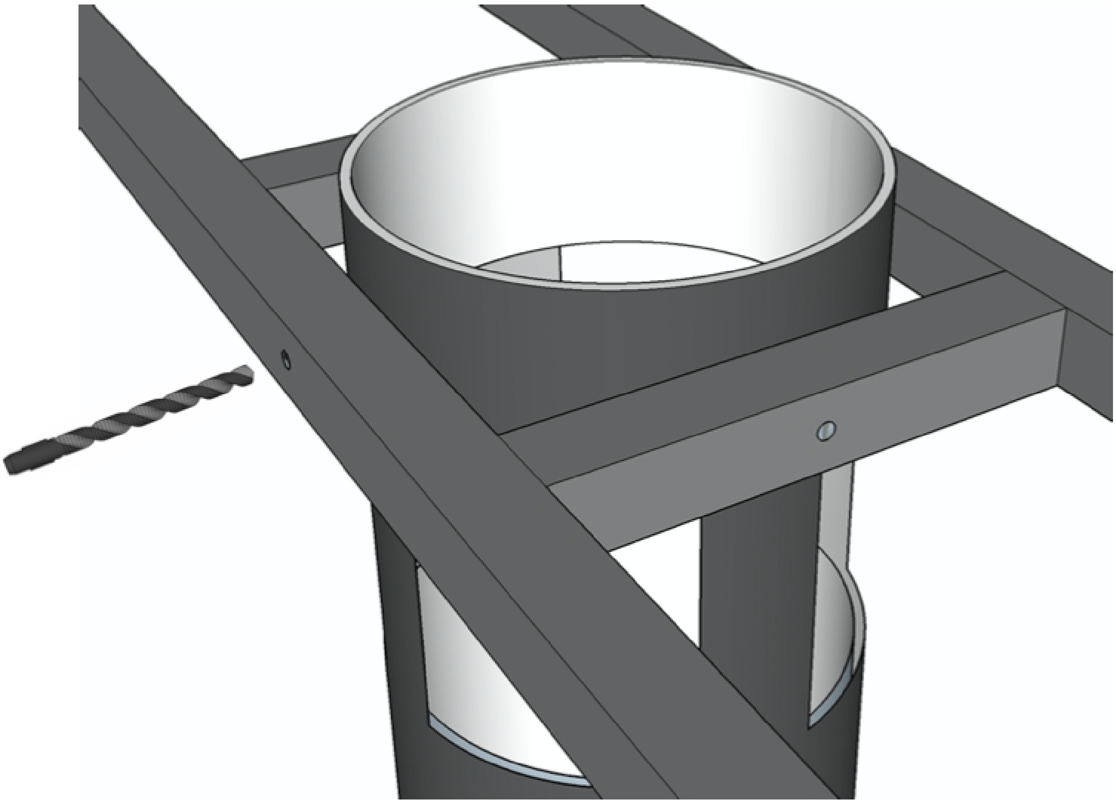
Mark the holes using the hinges on the solar panel with a pencil or drill them directly through the hinges.



First attach the hinges to the solar panel. Then drill the holes for the hinges in the metal frame. For this step join the solar panel to the metal frame and drill the holes directly through the hinges. This ensures that the solar panel and the metal frame fit together. Mark the upper side (side of the solar panel) on the metal frame for later assembly of the SOS.

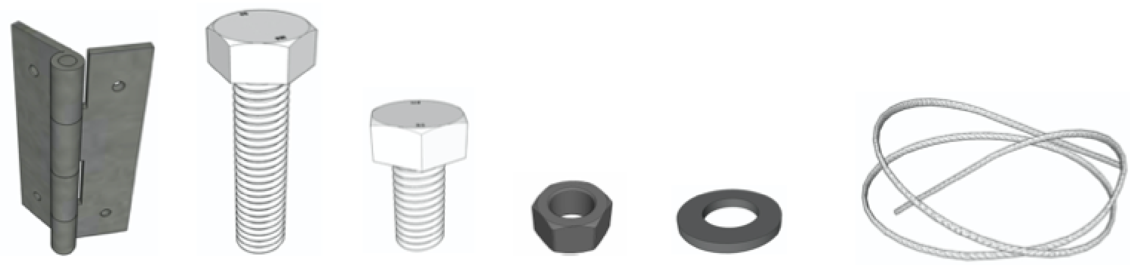
Pipe cut-out





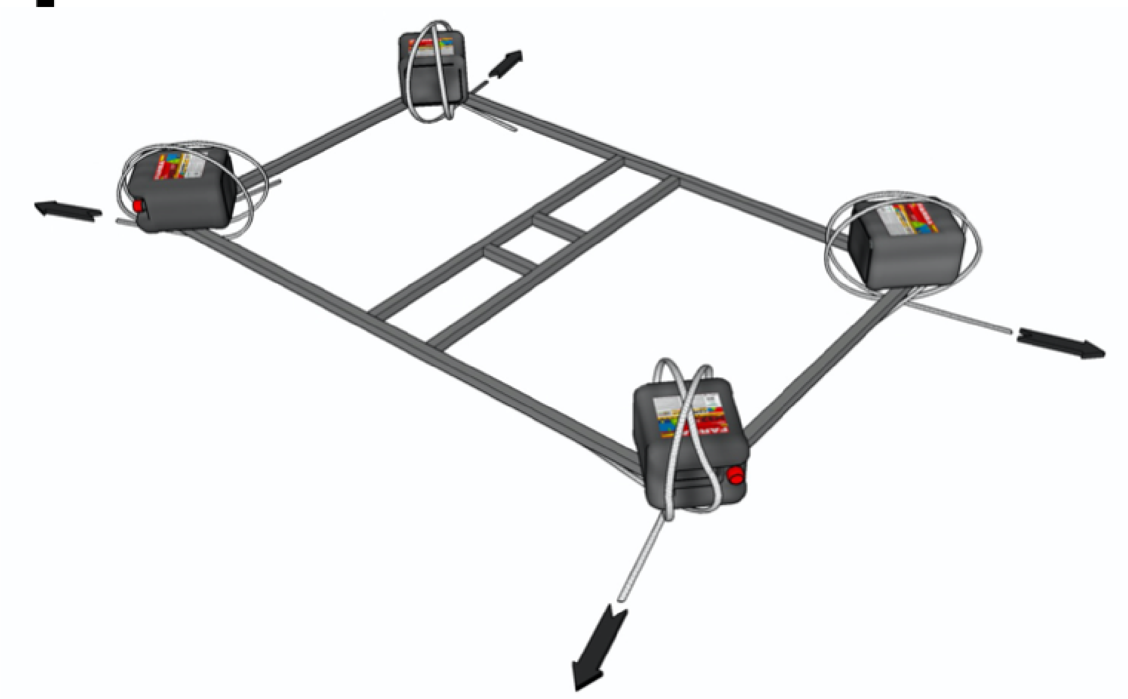
For the sake of simplicity and so that the holes in the metal frame match the holes in the PVC-pipe, the PVC-pipe should be drilled directly through the metal frame. For that the PVC-pipe should protude 24mm beyond the frame.

Construction manual



4x 4x 8x 12x 8x 4x

1



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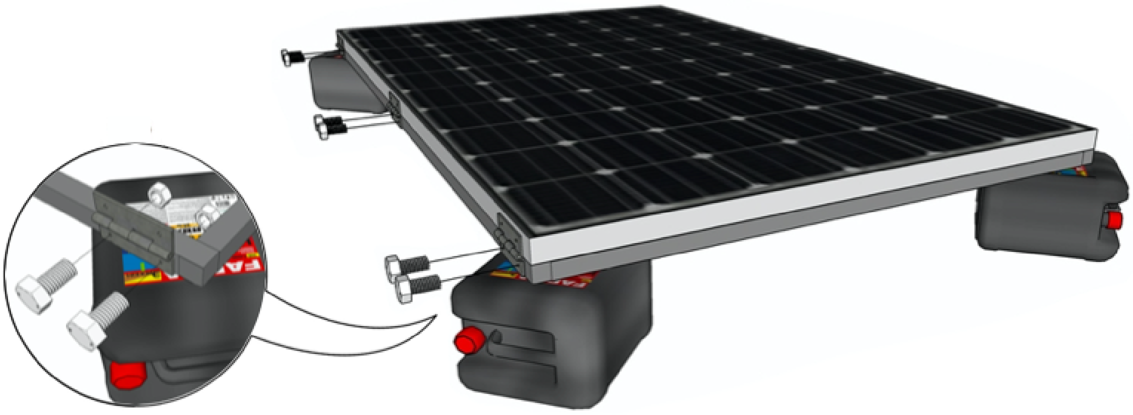

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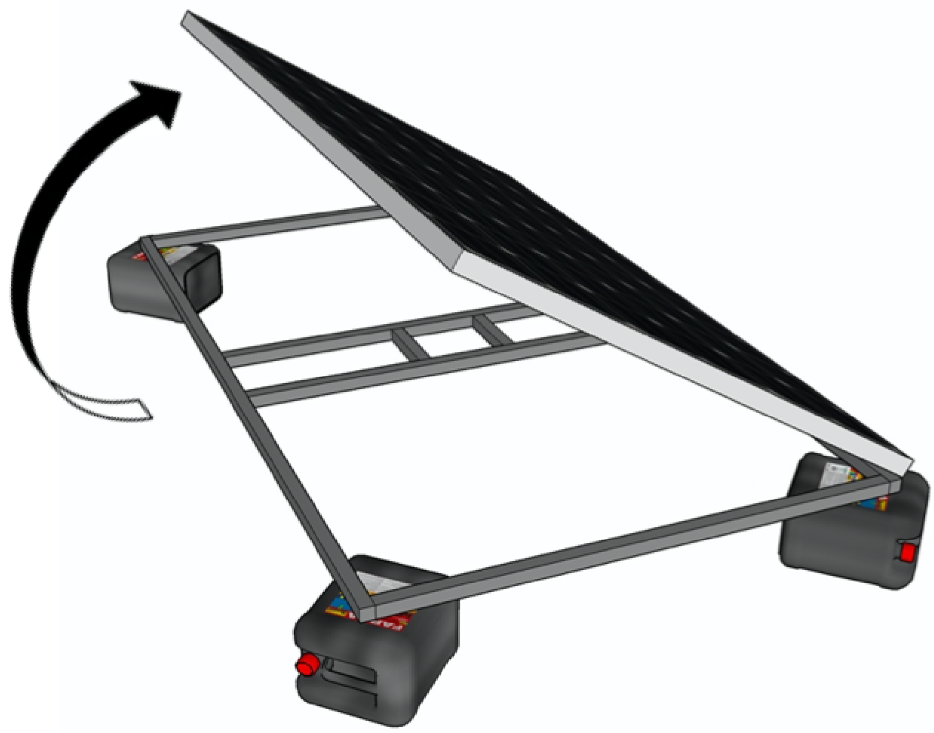

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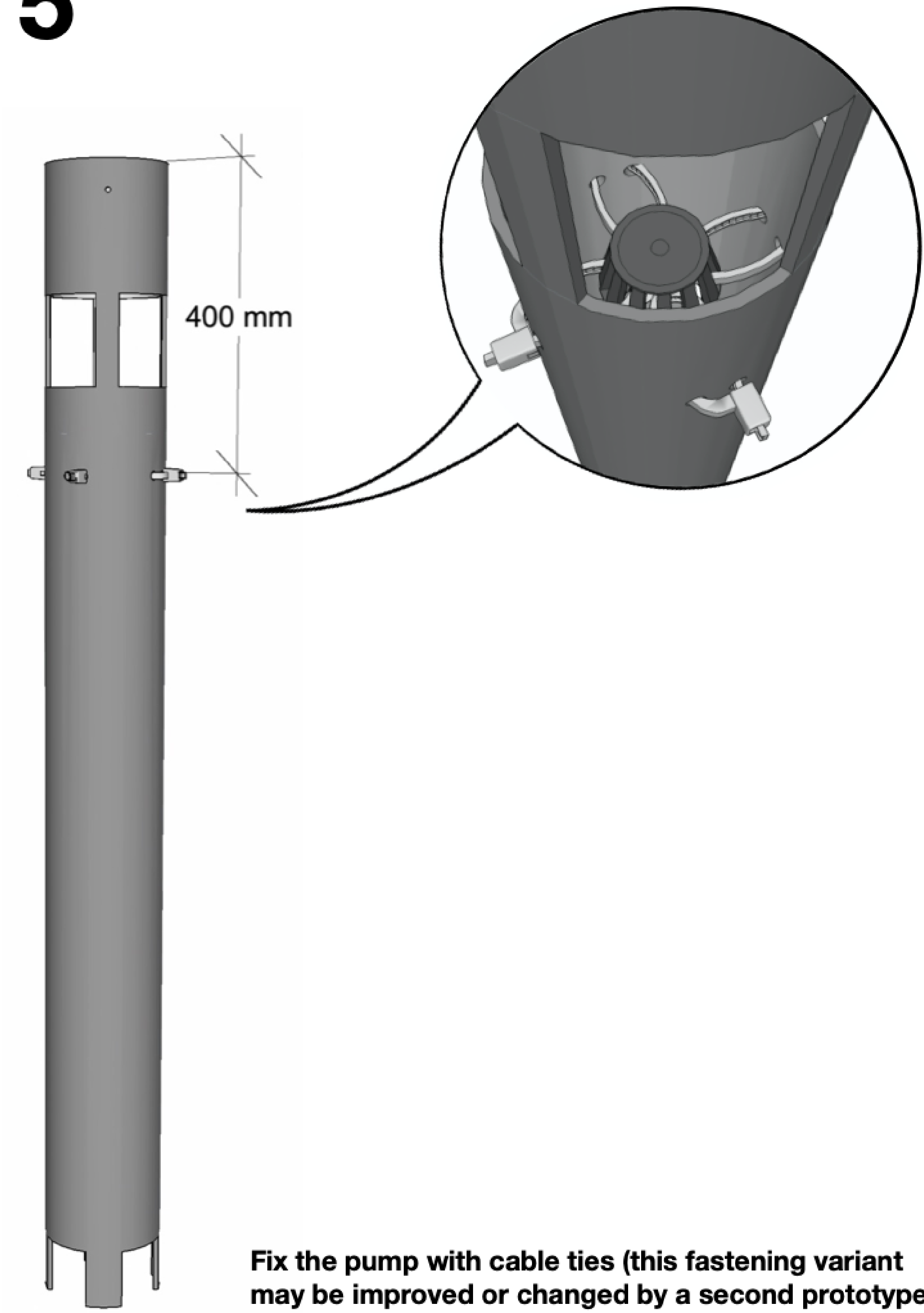
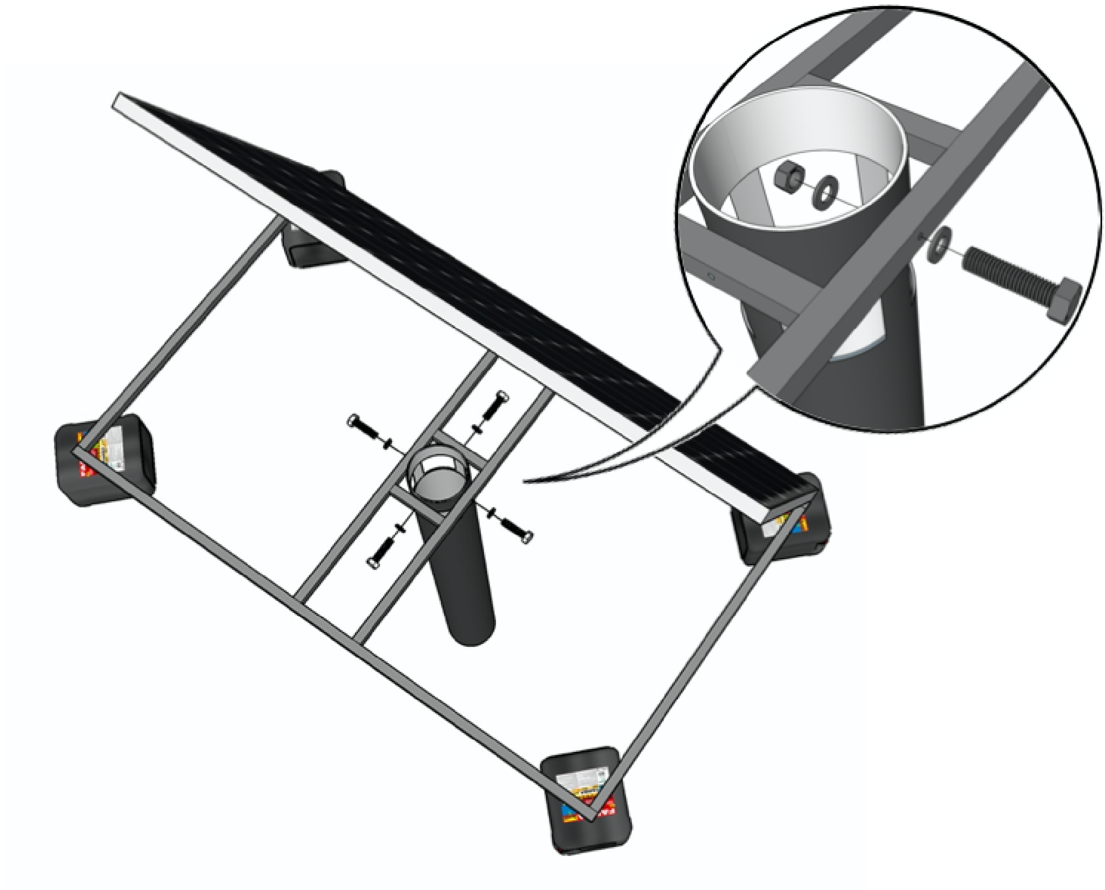


Fix the pump with cable ties (this fastening variant may be improved or changed by a second prototype).

6 The pump tube is only installed when the SOS is in the water.



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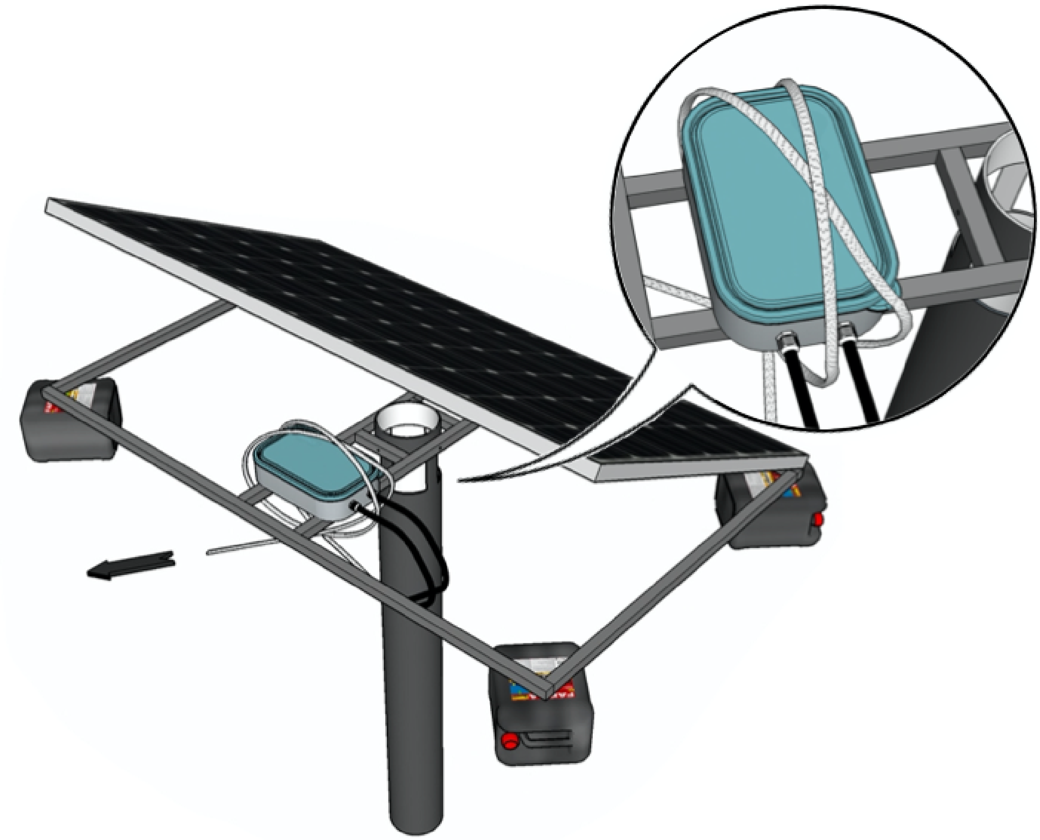

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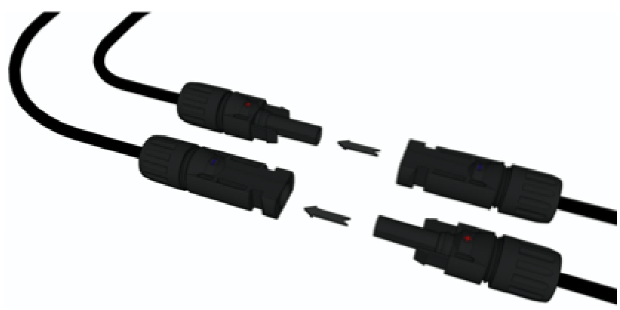


To prepare the electronics in the plastic box and to connect the SOS correctly us the SOP „SOS-Electricity".

These instructions for building the Sun Oxygen System may only used in conjunction with Smiling Gecko Cambodia. the manual may not be published elsewhere. For the illustration, graphics from Inter IKEA Systems were partly used.

Appendix B

Zürcher Hochschule für Angewandte Wissenschaften
Life Sciences und Facility Management
IUNR Institut für Umwelt und Natürliche Ressourcen

SOP SOS-ELECTRICITY

BACKGROUND

The Sun Oxygen System uses solar power to pump surface water in aquaculture ponds into deeper layers. To connect the integrated pump to the solar module, a step-down module and two fuses are installed. All electronic components are housed in a waterproof box. This SOP will show step by step how the electronic parts are installed.

PREPARING MATERIAL

- pump (RW-20)
- pump controller
- pumps Power supply unit
- step-down module
- luster terminal
- soldering iron
- solder
- wire stripper
- scalpel
- side cutter (scissors)
- plastic box
- cable gland
- MC4 plug

INSTRUCTION

Soldering

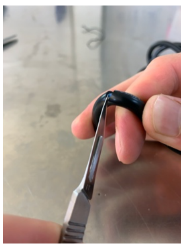
During soldering, make sure that the remaining solder on the soldering iron is removed from time to time with a damp paper towel. Caution: Danger of burns!

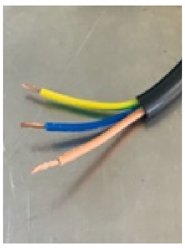
If the soldered joints are shiny, the soldered seam is good. If it appears dull, heat it again, as it is otherwise unstable.

Electronic components

1. Remove the plugs from the **pump** and the **pump controller**. Remove the plug of the **power supply** but make sure that 20 cm of the cable remains on the plug.

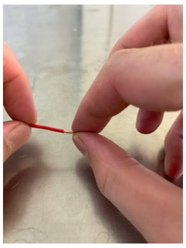
2. Remove 3 cm of outer cable from **pump**, **pump controls** and from the **plug of the power supply**. Use a wire stripper or a scalpel. By bending the cable the cutting with a scalpel is easier. When working with a scalpel, **be very, very careful** not to damage the inner cables.



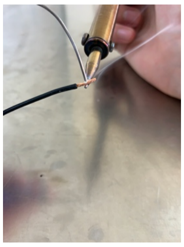


4. Remove 6 mm of the plastic sheathing from all open cables with a wire stripper.

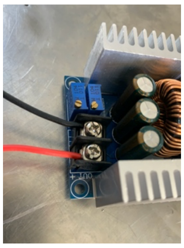
5. Twist all open copper wires with your fingers. Do it also with the open wires from the MC-4 plugs.



6. Put some solder on **all** the cable ends with the soldering iron.



7. Now connect the plug of the **power supply unit** to the Step-Down-Module. Make sure that the **red cable** is attached to the **OUT+** and **the black** cable to the **OUT-**. This steps are very important ! **If the pump and solar panel are connected incorrectly, the electronics may be damaged**.



8. Attach a luster terminal to the three cable ends of the pump controller.

Prepare the plastic box

1. Cut a hole in the middle of one side of the plastic box (Ø 12 mm).

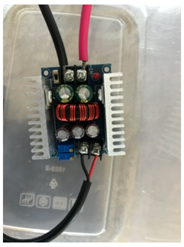
You can pre-drill it with a scalpel and then rub it out to the right size with a scissor.


2. Cut two holes on the other side of the plastic box in the same way.

3. Attach a cable gland by each hole.


4. Push the red and black cable of the MC-4 connectors through the two cable glands on one side. Now screw the cable glands tight so that the cables are sealed.

5. Attach the **red cable** of the MC-4 plug to the **IN-** from the step-down module and the **black cable** of the MC-4 plug to the **IN+** . **This steps are very important ! If the pump and solar panel are connected incorrectly, the electronics may be damaged**.

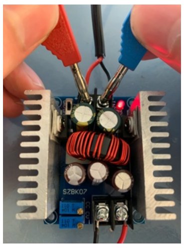


Setting the step-down module and install the electricity

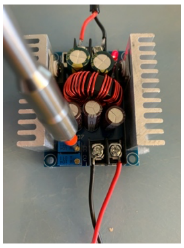
1. Connect the MC 4 plugs with the plugs from the solar panel.

2. Set the multimeter to measure direct current.

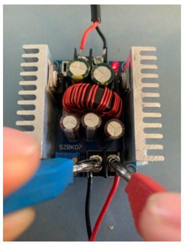
3. Measure the current at the step-down module. Measure only on the **IN** side which is connected to the solar panel. For that put the **red** cable to the **IN+** and the **blue** cable to the **IN-**. Make sure that a current of over 30V flows here. For that make sure that there is enough sunshine on the solar module.



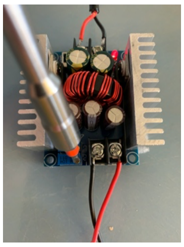
4. To adjust the current (amps), turn the upper adjustment screw clockwise until a click is heard. The current is now not limited.



5. Measure the current at the **OUT** output of the step-down module.
For that put the **red** cable to the **OUT+** and the **blue** cable to the **OUT-**.



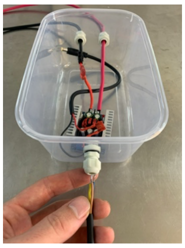
6. Now the voltage can be adjusted with the ideal lower adjusting screw. Turn the screw until the multimeter shows 24V.



The next steps should be done directly at the SOS in the water, if the pump and the pipe are already installed. Otherwise the cable of the pump should be removed again to install it at the SOS.

7. Connect the MC 4 plugs with the plugs from the solar panel.

8. Push the black cable of the pump through the cable glands on the other side. Now screw the cable gland tight so that the cable is sealed.



9. Now attach the three open cables of the pump to the luster terminal of the pump controller.

10. Then insert the plug of the step-down module at the **power** connection of the pump controller. Make sure that the pump mode from controller is **H** and the pump runs on **level 8**.

11. Close the plastic box. The electronics for the SOS are now completed and can be attached to the frame of the raft.

Appendix C

SOS Prices

Material	Quantity	Price $
Solar panel	1 piece	140
Pump	1 piece	95.09
Pipe	1.5 m	15
Step down Module	1 piece	11.5
Canister	4 pieces	6
Metal frame	7.4 m	5.3
Tupper	1 piece	3
MC4-Stecker	2 piece	2.5
Screw M5 35 mm incl. nut	9 pieces	1.71
Hinges	3 pieces	0.9
Cable gland	3 pieces	0.45
Screw M6 50 mm incl. nut	4 pieces	0.4
Washer	8 pieces	0.4
Cord	13.2 m	0.2
Zip ties	6 pieces	0.15
Total		**282.6**
Working hours Welder		5

Appendix D

Aqueous Ammonia Equilibrium: Tabulation of Percent Un-ionized Ammonia ((*https://agris.fao.org/agris-search/search.do?recordID=US7945902) and calculation from https://floridadep.gov/sites/default/files/5-Unionized-Ammonia-SOP_1.pdf)*

TABLE A-1 CONTINUED — TABLE PAGE 221

TEMP DEG C	8.60	8.61	8.62	8.63	8.64	PH 8.65	8.66	8.67	8.68	8.69	8.70
28.0	21.8	22.2	22.6	23.0	23.4	23.9	24.3	24.7	25.1	25.6	26.0
28.2	22.1	22.5	22.9	23.3	23.7	24.1	24.5	25.0	25.4	25.8	26.3
28.4	22.3	22.7	23.1	23.5	23.9	24.4	24.8	25.2	25.7	26.1	26.6
28.6	22.6	23.0	23.4	23.8	24.2	24.6	25.1	25.5	25.9	26.4	26.8
28.8	22.8	23.2	23.6	24.0	24.5	24.9	25.3	25.8	26.2	26.6	27.1
29.0	23.0	23.4	23.9	24.3	24.7	25.1	25.6	26.0	26.5	26.9	27.4
29.2	23.3	23.7	24.1	24.5	25.0	25.4	25.8	26.3	26.7	27.2	27.6
29.4	23.5	23.9	24.4	24.8	25.2	25.7	26.1	26.5	27.0	27.5	27.9
29.6	23.8	24.2	24.6	25.0	25.5	25.9	26.4	26.8	27.3	27.7	28.2
29.8	24.0	24.4	24.9	25.3	25.7	26.2	26.6	27.1	27.5	28.0	28.5
30.0	24.3	24.7	25.1	25.6	26.0	26.5	26.9	27.4	27.8	28.3	28.8
30.2	24.5	25.0	25.4	25.8	26.3	26.7	27.2	27.6	28.1	28.6	29.0
30.4	24.8	25.2	25.6	26.1	26.5	27.0	27.4	27.9	28.4	28.8	29.3
30.6	25.0	25.5	25.9	26.4	26.8	27.3	27.7	28.2	28.6	29.1	29.6
30.8	25.3	25.7	26.2	26.6	27.1	27.5	28.0	28.5	28.9	29.4	29.9
31.0	25.5	26.0	26.4	26.9	27.3	27.8	28.3	28.7	29.2	29.7	30.2
31.2	25.8	26.3	26.7	27.2	27.6	28.1	28.5	29.0	29.5	30.0	30.5
31.4	26.1	26.5	27.0	27.4	27.9	28.3	28.8	29.3	29.8	30.3	30.7
31.6	26.3	26.8	27.2	27.7	28.2	28.6	29.1	29.6	30.1	30.5	31.0
31.8	26.6	27.0	27.5	28.0	28.4	28.9	29.4	29.9	30.3	30.8	31.3
32.0	26.9	27.3	27.8	28.2	28.7	29.2	29.7	30.1	30.6	31.1	31.6
32.2	27.1	27.6	28.0	28.5	29.0	29.5	29.9	30.4	30.9	31.4	31.9
32.4	27.4	27.8	28.3	28.8	29.3	29.7	30.2	30.7	31.2	31.7	32.2
32.6	27.7	28.1	28.6	29.1	29.5	30.0	30.5	31.0	31.5	32.0	32.5
32.8	27.9	28.4	28.9	29.3	29.8	30.3	30.8	31.3	31.8	32.3	32.8
33.0	28.2	28.7	29.1	29.6	30.1	30.6	31.1	31.6	32.1	32.6	33.1
33.2	28.5	28.9	29.4	29.9	30.4	30.9	31.4	31.9	32.4	32.9	33.4
33.4	28.7	29.2	29.7	30.2	30.7	31.2	31.7	32.2	32.7	33.2	33.7
33.6	29.0	29.5	30.0	30.5	31.0	31.4	31.9	32.4	33.0	33.5	34.0
33.8	29.3	29.8	30.3	30.7	31.2	31.7	32.2	32.7	33.2	33.8	34.3
34.0	29.6	30.1	30.5	31.0	31.5	32.0	32.5	33.0	33.5	34.1	34.6
34.2	29.8	30.3	30.8	31.3	31.8	32.3	32.8	33.3	33.8	34.4	34.9
34.4	30.1	30.6	31.1	31.6	32.1	32.6	33.1	33.6	34.1	34.7	35.2
34.6	30.4	30.9	31.4	31.9	32.4	32.9	33.4	33.9	34.4	35.0	35.5
34.8	30.7	31.2	31.7	32.2	32.7	33.2	33.7	34.2	34.7	35.3	35.8
35.0	31.0	31.5	32.0	32.5	33.0	33.5	34.0	34.5	35.0	35.6	36.1

TABLE A-1 CONTINUED — TABLE PAGE 251

TEMP DEG C	9.10	9.11	9.12	9.13	9.14	PH 9.15	9.16	9.17	9.18	9.19	9.20
28.0	46.9	47.5	48.1	48.6	49.2	49.8	50.4	50.9	51.5	52.1	52.7
28.2	47.2	47.8	48.4	49.0	49.5	50.1	50.7	51.3	51.8	52.4	53.0
28.4	47.6	48.2	48.7	49.3	49.9	50.5	51.0	51.6	52.2	52.8	53.3
28.6	47.9	48.5	49.1	49.7	50.2	50.8	51.4	52.0	52.5	53.1	53.7
28.8	48.3	48.9	49.4	50.0	50.6	51.2	51.7	52.3	52.9	53.5	54.0
29.0	48.6	49.2	49.8	50.4	50.9	51.5	52.1	52.7	53.2	53.8	54.4
29.2	49.0	49.5	50.1	50.7	51.3	51.8	52.4	53.0	53.6	54.1	54.7
29.4	49.3	49.9	50.5	51.0	51.6	52.2	52.8	53.3	53.9	54.5	55.1
29.6	49.7	50.2	50.8	51.4	52.0	52.5	53.1	53.7	54.2	54.8	55.4
29.8	50.0	50.6	51.1	51.7	52.3	52.9	53.4	54.0	54.6	55.2	55.7
30.0	50.3	50.9	51.5	52.1	52.6	53.2	53.8	54.4	54.9	55.5	56.1
30.2	50.7	51.3	51.8	52.4	53.0	53.6	54.1	54.7	55.3	55.8	56.4
30.4	51.0	51.6	52.2	52.7	53.3	53.9	54.5	55.0	55.6	56.2	56.7
30.6	51.4	51.9	52.5	53.1	53.7	54.2	54.8	55.4	55.9	56.5	57.1
30.8	51.7	52.3	52.9	53.4	54.0	54.6	55.1	55.7	56.3	56.8	57.4
31.0	52.0	52.6	53.2	53.8	54.3	54.9	55.5	56.0	56.6	57.2	57.7
31.2	52.4	53.0	53.5	54.1	54.7	55.2	55.8	56.4	56.9	57.5	58.1
31.4	52.7	53.3	53.9	54.4	55.0	55.6	56.1	56.7	57.3	57.8	58.4
31.6	53.1	53.6	54.2	54.8	55.3	55.9	56.5	57.0	57.6	58.2	58.7
31.8	53.4	54.0	54.5	55.1	55.7	56.2	56.8	57.4	57.9	58.5	59.1
32.0	53.7	54.3	54.9	55.4	56.0	56.6	57.1	57.7	58.3	58.8	59.4
32.2	54.1	54.6	55.2	55.8	56.3	56.9	57.5	58.0	58.6	59.1	59.7
32.4	54.4	55.0	55.5	56.1	56.7	57.2	57.8	58.4	58.9	59.5	60.0
32.6	54.7	55.3	55.9	56.4	57.0	57.6	58.1	58.7	59.2	59.8	60.3
32.8	55.1	55.6	56.2	56.8	57.3	57.9	58.5	59.0	59.6	60.1	60.7
33.0	55.4	56.0	56.5	57.1	57.7	58.2	58.8	59.3	59.9	60.4	61.0
33.2	55.7	56.3	56.9	57.4	58.0	58.5	59.1	59.7	60.2	60.8	61.3
33.4	56.1	56.6	57.2	57.7	58.3	58.9	59.4	60.0	60.5	61.1	61.6
33.6	56.4	56.9	57.5	58.1	58.6	59.2	59.7	60.3	60.8	61.4	61.9
33.8	56.7	57.3	57.8	58.4	59.0	59.5	60.1	60.6	61.2	61.7	62.3
34.0	57.0	57.6	58.2	58.7	59.3	59.8	60.4	60.9	61.5	62.0	62.6
34.2	57.4	57.9	58.5	59.0	59.6	60.2	60.7	61.3	61.8	62.3	62.9
34.4	57.7	58.3	58.8	59.4	59.9	60.5	61.0	61.6	62.1	62.7	63.2
34.6	58.0	58.6	59.1	59.7	60.2	60.8	61.3	61.9	62.4	63.0	63.5
34.8	58.3	58.9	59.5	60.0	60.6	61.1	61.7	62.2	62.7	63.3	63.8
35.0	58.7	59.2	59.8	60.3	60.9	61.4	62.0	62.5	63.0	63.6	64.1

Appendix E

Assignment of the bachelor thesis

Zürcher Hochschule
für Angewandte Wissenschaften

Life Sciences und Facility Management

Institut für Umwelt und Natürliche Ressourcen

<table>
<tr><th colspan="3">Bachelor-Arbeit</th></tr>
<tr><td colspan="2">Studienjahrgang</td><td>UI17</td></tr>
<tr><td colspan="2">Titel</td><td>Sauerstoffversorgung in Fischzuchtteichanlagen</td></tr>
<tr><td colspan="2">Vertraulich</td><td>ja   nein X</td></tr>
<tr><td colspan="2">Forschungsgruppe</td><td>Aquakultur-Systeme</td></tr>
<tr><td>Namen</td><td>StudentIn</td><td>Jonathan Konrad
konrajon@students.zhaw.ch</td></tr>
<tr><td></td><td>KorrektorIn</td><td>Fridolin Tschudi tsci@zhaw.ch
Luca Regazzoni regz@zhaw.ch</td></tr>
<tr><td colspan="2">Aufgabenstellung
Ausgangslage
Zielsetzungen
Zusätzliche Auftrags-modalitäten</td><td>Aufgabenstellung

Neben anderen Projekten, betreibt die NGO Smiling Gecko Cambodia mithilfe der ZHAW-Forschungsgruppe Aquakultursysteme eine Tilapia-Zucht nördlich von Phnom Penh. Diese Anlage wird aktuell mit Paddle-Wheels betrieben, welche auf eine permanente Stromversorgung zu Nachtzeiten angewiesen sind.

Für die Replizierung der integrierten Teichwirtschaft bei Kleinbauern wird ein Sauerstoff-Eintragssystem benötigt, welches nicht auf eine permanente Stromversorgung angewiesen ist. Ohne ein derartiges System ist nur eine unbelüftete Teichwirtschaft mit geringer Produktivität möglich.
In Zukunft soll die Sauerstoffversorgung kleiner Teiche ohne Stromversorgung ökologisch, nachhaltig und wirtschaftlich interessant bewerkstelligt werden können. Hierfür wird ein neuartiges System getestet, welches mithilfe von Solarstrom das durch Algen mit Sauerstoff angereicherte Oberflächenwasser im Zuchtteich in tiefere Wasserschichten pumpt um so die Sauerstoffkonzentration in der Wassersäule zu erhöhen. Das sogenannte SOS (Sun Oxygen System) soll innerhalb dieser Arbeit vor Ort getestet und validiert werden.

Zu diesem Zweck fokussiert sich die Bachelorarbeit auf zwei Teilbereiche:
Sauerstoffzufuhr
Fütterungsversuch</td></tr>
</table>

Eine Literaturrecherche soll zu Beginn der Arbeit Hintergrundinformationen liefern über die Tilapia-Zucht deren Sauerstoffversorgung und über das zu testende Sun Oxygen System.
Anschliessend wird in einem ersten Schritt die Sauerstoffverteilung in Teichsystemen mit und ohne SOS ermittelt. Dafür wird ein zeitliches und räumliches Sauerstoffprofil der Testteiche erstellt. Die Resultate werden anschliessend miteinander verglichen.
Anhand dieser Resultate soll nun das Setting für einen Fütterungsversuch mit Tilapia aufgebaut werden.
Für den Fütterungsversuch stehen 6 Ponds zur Verfügung.
Es werden drei Teiche mit einem SOS und drei Teiche ohne ein SOS (Naturteich ohne Belüftung) betrieben. Die Fische werden während des Versuches nach einem Futterprotokoll gefüttert, welches vorsieht, dass bei tiefem Sauerstoffgehalt nicht gefüttert wird. Die Fütterung ist somit limitiert durch die Sauerstoffverfügbarkeit.
Da die Sauerstoffkonzentration im Wasser einen signifikanten Einfluss auf das Wachstum, die Futterverwertung und die Mortalität von Fischen hat, kann auf diese Weise der direkte Nutzen des SOS ermittelt werden. Hierfür werden während der Versuchszeit anhand des Futter- und Fischgewichtes die Wachstumsrate und die Futterverwertungsrate der Fische in den unterschiedlich belüfteten Ponds berechnet.
Während des Versuches sollen weitere Parameter wie Sonneneinstrahlung, Wassertemperatur, pH-Wert, Leitfähigkeit, Redox, CSB, NO_2^- und $NH_{4,}$ NO3, Ptot, PO4, UV-Adsorpoton, Chlorphyllgehalt, TSS, TOC, DOC überprüft werden. Weiter soll das Teichwasser mikroskopische analysiert werden. Die so gewonnenen Messdaten sollen die Resultate der Arbeit unterstützen sowie Aufschluss über die vorhandene Wasserqualität geben.
Eine Kosten-Nutzen-Analyse soll die Arbeit abschliessen und den allfälligen direkten Zusatznutzen eines Sun Oxygen System im Vergleich zu einem unbelüfteten Teich beziffern.

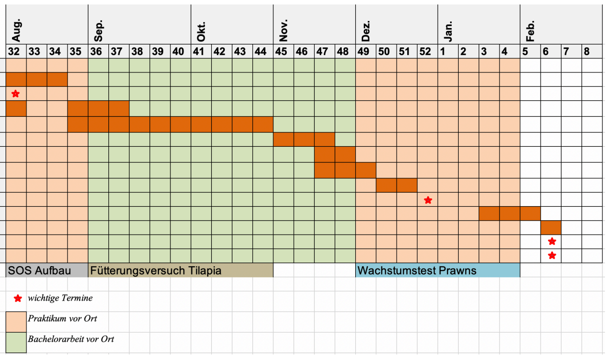
Provisorisches Inhaltsverzeichnis

Formale Anforderungen	Alle relevanten Merkblätter zu studentischen Arbeiten
Zeitplan	*(siehe Excel-Tabelle unten)*
Abgabetermin **(12.00 Uhr)**	*14.01.2021 (oder Verlängerung bis KW 6)*
Bemerkungen	-
Arbeitsort	Kambodscha

Zeitplan provisorisch

Zeitplan BA / Praktikum Kambodscha

Phas	Tätigkeit	[h]	Termin
1	Literaturrecherche / Theorieteil (vorgezogen)	50	
2	**Feinplanung Futterprotokoll von Luca / Messkonzept**	10	**KW 32**
3	Material / Methode	50	
4	Datensammlung	120	
5	Datenauswertung / Vergleich	50	
6	Resultate	30	
7	Diskussion	50	
8	Überarbeitung	30	
9	**Abgabe Rohfassung**		**KW 52**
10	Überarbeitung	40	
11	Korrektur/Gegenlesen	6	
12	**Vortrag Bachelorarbeit**	16	**KW 6**
13	**Letztmöglicher Abgabetermin Endfassung**		**KW 6**
	povisorische Hauptschwerpunkte gemäss Ben Scott		
Totaler Zeitaufwand		**452**	



Plagiate verstossen gegen die Urheberrechte, eine Verletzung dieser Rechte wird gemäss der Studien- und Prüfungsordnung für die Bachelorstudiengänge der Hochschule Wädenswil vom 01.09.2006 in § 38, 39 geregelt. Diese Studien- und Prüfungsordnung gilt für alle Bachelorstudienjahrgänge bis und mit Studienstart 2009.

Für Bachelorstudienjahrgänge mit Studienbeginn ab 2010 und die Masterstudiengänge mit Studienbeginn ab 2009 gilt § 39 der Rahmenprüfungsordnung für Bachelor- und Masterstudiengänge an der Zürcher Hochschule für Angewandte Wissenschaften vom 29.01.2008.

Appendix F

Poster

Sun Oxygen System

Bachelor thesis, Jonathan Konrad, Bachelor programme Environmental Engineering 2017

Zürcher Hochschule für Angewandte Wissenschaften
Life Sciences und Facility Management
IUNR Institut für Umwelt und Natürliche Ressourcen

Introduction

Fish from aquaculture is becoming increasingly important for global food security. For the Cambodian population, fish is the most important source of animal protein. In 2014, Smiling Gecko Cambodia (SGC) was founded as a local NGO in Cambodia with the aim of supporting the local population with direct aid and sustainable help for self-help. Through cooperation with the Zurich University of Applied Sciences, the Smiling Gecko Fish Project was launched 4 years later. In order to promote the education and income of surrounding smallholder women farmers and to counteract gender inequality, the Woman in Aquaculture project was launched. The Sun Oxygen System (SOS) was developed by the ZHAW to enable the planned fish breeding ponds to be aerated independently of the electricity grid. A pump powered by a solar panel transports the surface water, which is supersaturated with oxygen through photosynthesis by algae, into deeper layers. In this way, the excess oxygen does not immediately diffuse into the ambient air but can be stored for longer by the entire water column. The aim of this work is to validate the Sun Oxygen System on site in Cambodia. For this purpose a feeding trial with tilapias will be launched on the premises of Smiling Gecko Cambodia. For this field trial, 2 stocked fish ponds are available. One of them are to be managed with an SOS and the other without. Daily monitoring of the DO concentrations in the water, the fish behaviour and the SOS runtime will be used to evaluate the performance and added value of the Sun Oxygen System. Chemical water parameters will be collected to check the water quality during the trial. Due to excessive oxygen consumption at night and a clogged SOS pump, the trial was split into two trials (Trial A & B). For this poster only the methodology and resaults of Trial B were considered.

Material & Methods

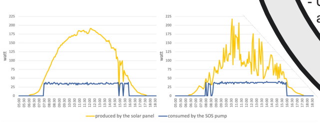
Two ponds were available for the field trial, which were lined with pond liners in advance. The fish ponds were filled with 468 m3 water to a depth of 2.6 m with water from the neighbouring tilapia farm. For Trial B 243 kg of Nile tilapias (250 g) were transfered to the ponds. This corresponded to a fish density of 0.5 kg/m3 and 0.9 kg/m2. In the middle of one pond a SOS was fixed with a rope. DO concentration, saturation and water temperature were measured 4 times a day (06:30, 09:30, 13:30, 15:30) at depths of 0.02, 0.5, 1 and 2 m. In order to get a more accurate picture of the DO distribution, the DO concentration was additionally measured twice a week in the entire pond in the same water depths but on five different measuerement points. For monitoring the SOS performance the current of the running pump motor was measured. Also the solar radiation was recorded. In advance the radiation at which the SOS pump starts up was tested. This information made it possible to detremine the daily SOS running time.

Conclusion

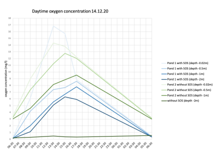
During the Trial verry low DO concentrations are found in the pond with SOS. Because of the used pondwater whitch was rich in phytoplankton and nutrients it can be assumed that oxygen consuming substances such as dead phytoplankton, sediments and fish faeces were kept in suspension by the water circulation of the SOS and thus led to a reduction in the DO concentration. It is also conceivable that sedimented material in the form of mud was transported by the submersible pump when filling the ponds. For the above reasons, it is recommended that further SOS tests are carried out in water with less nutrients. Further adjustments and ideas were suggested for future tests:

- Short the SOS Pipe or close it an make lateral outlets, so the pump stirs up less sediments from pond bottom.
- Active removal of sediments with the help of a settling tank.
- Using a stepless pump motor that adjusts the speed to the available energy.
- Using of the energy surplus for other applications.
- A maintanace / cleaning plan for the solar panel to prevent powerful leg bumps.
- Waste managment and security measures for children and animals.

SOS-Performance

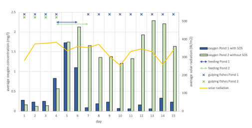


A comparison of a day under sunny sky with a day under cloudy sky shows how many watts were produced by the solar panel and how much was consumed by the running SOS. On a nice day, the solar panel produced 1.15 kWh of energy while the SOS pump consumed 0.29 kWh. On a cloudy day, the panel produced 0.71 kWh and the pump consumed 0.28 kWh. This results in an energy surplus of 0.86 kWh on a nice day and 0.43 kWh surplus on a cloudy day.

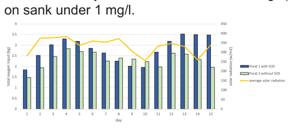


One of the daytime DO concentration graph shows that the DO concentration in the morning in the pond with SOS is very low. At dusk at 17:30 the DO concentrations in all depths in the pond with SOS are close together while in the pond without SOS a stratification is clearly visible. Through the stratification an anaerobic layer could build in the depth of 2 m in the pond without SOS. This is an indication that oxygen-consuming substances sediment and accumulate at the bottom of the pond. Because of the well mixed pondwater this did not happend in the pond with SOS. All the oxygen-consuming substances are well distributed in the entire water column in the pond.

Feeding Trial



The Results from the trial show that the morning DO concentrations in both ponds rose briefly after the trial started. From day 7 onwards, however, the concentrations in Pond with SOS were below 0.5 mg/l daily. Because of the oxygen levels being too low the feeding trial was stopped on this day. The DO concentrations in the pond without SOS were always above 1 mg/l from day 5 onwards and rose to over 2 mg/l in some cases. It was also clearly visible that the fishes were gulping when the DO concetration sank under 1 mg/l.



The daily oxygen input is shown in the next graph. In the pond equipped with an SOS, the total input is only from day 8 to day 10 below the input calculated for the pond without SOS. A comparison of all daily oxygen inputs shows that during the two weeks of Trial B, on average 0.48 kg more oxygen was enriched in the pond water in the pond with SOS than in the pond without SOS. The weighing of the fish for the feeding trial did not yield any useful data, as the feeding was stopped early. Also the sample size of the weighed fish in the trial was considered too small to calculate a representative average weight, as the scatter of the weights was with a average standard deviation of 43.95 g too large.

Appendix G

Declaration of independence

Erklärung betreffend des selbstständigen Verfassens einer Bachelorarbeit im Departement Life Sciences und Facility Management.

Mit der Abgabe dieser Bachelorarbeit versichert der/die Studierende, dass er/sie die Arbeit selbständig und ohne fremde Hilfe verfasst hat.

Der/die unterzeichnende Studierende erklärt, dass alle verwendeten Quellen (auch Internetseiten) im Text oder Anhang korrekt ausgewiesen sind, d.h. dass die Bachelorarbeit keine Plagiate enthält, also keine Teile, die teilweise oder vollständig aus einem fremden Text oder einer fremden Arbeit unter Vorgabe der eigenen Urheberschaft bzw. ohne Quellenangabe übernommen worden sind.

Bei Verfehlungen aller Art treten Paragraph 39 und Paragraph 40 der Rahmen-prüfungsordnung für die Bachelor- und Masterstudiengänge an der Zürcher Hochschule für Angewandte Wissenschaften vom 29. Januar 2008 sowie die Bestimmungen der Disziplinarmassnahmen der Hochschulordnung in Kraft.

Ort, Datum:

Bremgarten 08.02.21 ....

[redacted]